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Technical note
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NAVAL UNDERSEA RESEARCH AND DEVELOPMENT CENTER

COMPUTER TARGET CLASSIFICATION AND THREAT EVALUATION IN ADVANCED ACTIVE SONAR SYSTEMS

by

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FOREWORD

The work documented in this technical note resulted in the design and software implementation of a computer-assisted target classification and threat evaluation system. As conceived, this system is an integral subsystem of a larger data processing system for an advanced submarine or surface ship sonar.

All work on this project was done at this Center (then known as the Naval Undersea Warfare Center, San Diego) from January through December 1968. The work was sponsored by NAVSHIPSYSCOM (Code OOV2), with the major portion supported through the New Submarine Sonar/Fire Control System Project Office. Limited support was also provided by OOV2 through the Conformal/Planar Array Program Project Office.

This technical note describes only one of the approaches investigated. A promising alternative approach is separately documented in NUC Technical Note 542.[1]

The author wishes to acknowledge the technical guidance of R. P. Schindler (presently of NELC) and the programming support of R. Napier (presently of IBM), M. Einhorn and C. Lightfoot of Computer Sciences Corporation.

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1 Superscript numbers denote references at end of technical note.

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I. INTRODUCTION

With the advent of large computerized sonar systems for advanced submarine and surface ship platforms, the familiar target classification clues will be supplanted for the most part by vast amounts of digitized multi-sensor information.

For the sonar operator or watch commander to effectively select and correlate pertinent target data under such circumstances, it becomes imperative that computerized techniques be developed to assist in the classification and threat analysis decision-making processes.

This technical note describes a straightforward deterministic approach to the problem of computer-assisted target classification and threat evaluation. The result is the design of a prototype system which automatically provides the sonar operator with operationally useful target classification and threat evaluation information.

The use of man-machine interaction to solve such complex problems as target classification or threat evaluation involves enormous difficulties. Nevertheless, the effort documented here represents essential groundwork for the development of even more sophisticated deterministic classification and threat evaluation systems.

II. AUTOMATIC TARGET CLASSIFICATION AND THREAT EVALUATION

A. Advanced Active Sonar Systems

It is anticipated that the sonar systems currently under development by the Navy for advanced submarine and surface ship platforms will employ sohpisticated computerized data processing complexes (DPC). These complexes will be programmed to correlate data from active and passive sonar sensors with environmental data, own-ship's status, system performance levels, and intelligence information. Computer programs for the DPC will also perform, with varying degrees of operator assistance, the functions of target detection, tracking, classification, threat evaluation, and will provide fire control solutions and weapon settings. In addition, the DPC system will drive multiple display consoles to provide digital and graphic formats for sonar, fire control, and command and control personnel.

In this technical note only the classification and threat evaluation functions of the DPC are considered. These are treated as a functional subsystem of the DPC: the Active Classification and Threat Evaluation Subsystem (ACTS). As a subsystem, the ACTS is subject to certain system-imposed constraints. For example, the ACTS must operate on a "real-time" basis in the sense that it must process the information from a ping and produce estimates of target classification and threat level as rapidly as possible. This is done to allow the DPC to incorporate the ACTS information into its fire control and weapon settings solutions and generate the necessary display formats before arrival of data from the next ping. Also, the individual programs in the system of programs which perform the functions of target classification and threat evaluation must not be allowed to consume operating time or core memory space out of proportion to their importance to total operational effectiveness.

B. Measurement Extraction and Processing

The ACTS is designed to extract a large number of target measurements each ping from detected targets of unknown class. These measurements are then combined and processed to produce a set of "target parameters" for each target. The processing referred to here might typically be that of computing the target depth parameter from extracted measurements of multipath target separation distance, and own-ship's transmission angle.[2]

C. Classification Techniques

There are numerous techniques available for utilizing the target parameters information to obtain estimates of the target class and target threat level. One approach to target classification would be to treat the target parameter values, after suitable normalization, as components of an n-dimensional vector of unknown class. Classification in this case would consist of assigning this unknown vector to the set of previously classified vectors to which it is closest, in some sense, in an n-dimensional vector space. This approach has its foundations in statistical decision theory and can be implemented as an adaptive structure. This would be highly desirable in the case where the input data are known to be nonstationary. However, a disadvantage of this technique is that it requires the acquisition, storage, and processing of representative data from each target class. High-quality representative data are, unfortunately, very difficult to obtain and compromises involving artificial data would have to be anticipated.[2]

[1]Superscript numbers indicate references presented at end of this technical note.

An alternate approach, and the one that is employed in the ACTS, is to design a nonadaptive structure containing fixed mathematical descriptions of the target classes and threat levels that require identification. There is little potential in such a system design for automatic learning or adaptation to nonstationarity in the data. However, this system configuration has the advantage that the classification and threat level evaluation functions are reduced to performing high-speed computer evaluations of a small number of nonvarying mathematical functions. Also, there is no requirement for large-scale storage of real and artificial multidimensional data of known classification.

D. Operational Considerations

The act of making a target classification will continue to be a high-level decision process in advanced submarine and surface ship sonar systems. Basically, this decision consists of determining whether a detected target is hostile or friendly and to which of the following groups it belongs: submarine, surface ship, weapon, countermeasure or other. Actual target classification decisions are too crucial and the cost of a false alarm too high to permit such decisions to be made completely by means of a computer. Therefore, final classification decisions will continue to be made by the highest ranking officer having access to the sonar sensor, environmental sensor, operational and intelligence data. However, computer assistance is essential to the classification decision-making function, since it processes and correlates vast quantities of multisensor data and provides rapid automatic estimates of target class and threat level.

The ACTS will automatically compute and display estimates of target class and threat level on a once-per-ping basis for newly detected targets and for targets which are currently being actively tracked. Ideally, the ACTS would unerringly label each target with the correct class each ping. Realistically, the best that can be done automatically is to provide relative estimates of class membership and corresponding threat level evaluations. The primary function of the ACTS, therefore, is to provide a ranking of likely target classes and an evaluation of their threat levels. These can be used as inputs to a classification operator or may be thresholded to provide an automatic alarm, or perhaps even to initiate evasive platform maneuvers and to arm weapons. Thus, the ACTS exemplifies a priority function within the DPC due to the frequency of its operation and to the fact that the sonar platform may well be in a race with a hostile computer to classify targets and establish fire control solutions.

III. ACTIVE CLASSIFICATION AND THREAT EVALUATION SUBSYSTEM DESIGN

The concepts embodied in the design of the ACTS can best be described by referring to Figure 1, a system block diagram. This diagram shows the sources of input data to the ACTS, the sequence of internal processing operations, and the treatment of the classification and threat evaluation outputs.

A. Input Data

Under normal operating conditions, the inputs available each ping to the ACTS include split-beam tracking data, preformed beam data, fine tracking data, and several different types of external information. Data from the split-beam tracker will be in the form of electrical degrees of phase between returns from the two halves of the split-tracking beam. Fine angular resolution will be achieved by associating the essentially linear electrical phase values between ±90° with angular degrees in the interval of ±2.5°, or one-half of the width of the split beam. These angular degrees will correspond to bearing or depression angle depending on whether the beam is split in the horizontal or vertical plane. For a tracking beam which can be split in both planes and has a 1000-yard range gate with 4-yard range resolution, 250 range-versus-bearing samples and 250 range-versus-depression angle samples would be generated each ping. It is anticipated that an additional 250 range-versus-amplitude samples can also be obtained each ping by sampling the split-beam processing hardware ahead of the digital correlators.

The preformed beam array will also produce digital data for the ACTS each ping. These data will be digitized and thresholded so that the range resolution elements with amplitudes exceeding a threshold will be passed while those elements with amplitudes less than the threshold will be set to zero. Thus, the preformed beam data, for a 1000-yard range gate with 4-yard range resolution, will consist of approximately 250 thresholded amplitudes along each of about 20 doppler channels for each preformed beam. Only the beam most closely corresponding to the target's bearing, plus adjacent beams containing side-lobe structure information, will be transmitted to the ACTS.

A system of programs for automatic track detection and fine tracking will be incorporated into the DPC and will provide valuable inputs to the ACTS. The outputs of the fine tracker program which will be used by the ACTS are listed in Table 1. The items listed in this table are self-explanatory with the exception of maneuver identification. This quantity is set to 1 whenever the fine tracker's computation of the target's projected position proves to have been in error in excess of a selected threshold value. In this case, the tracker's parameters must be reinitialized and a target maneuver is assume to have occurred.

The final group of ACTS inputs is termed external information and contains environmental, sonar system, own-ship's status and target intelligence data. The external information inputs are itemized in Table 2.

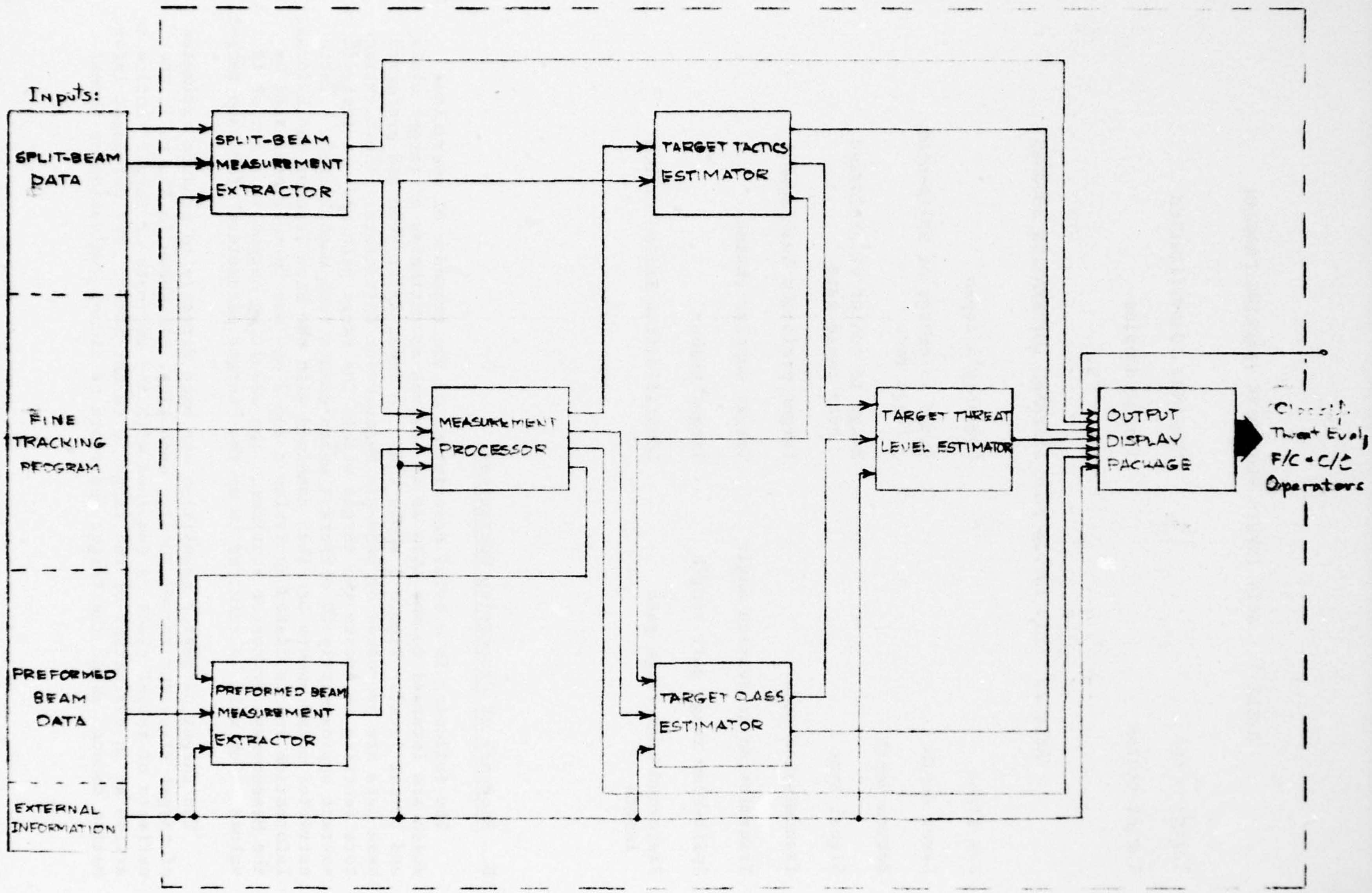

FIGURE 1. Active Classification and Threat Evaluation Subsystem (ACTS)

TABLE 1. ACTS INPUTS FROM FINE TRACKING PROGRAM

Target speed	Maneuver identification
Target course	Target doppler

TABLE 2. ACTS INPUTS FROM EXTERNAL INFORMATION SOURCES

Sea state	Own-ship's depth
Layer depth	Range to center of split-beam range gate
Bottom depth	Range to center of preformed beam range gate
Signal type	
Transmission mode	Target preformed beam number
Transmission depression angle	Target doppler channel
Split-beam range gate length	Target number
Preformed beam range gate length	Identification Friend or Foe

B. Sequence of Processing Operations

The following is a brief description of the sequence of operations which are internal to the ACTS as it arrives at estimates of target class and threat level. Figure 1 shows that the input split-beam and preformed beam data are processed by separate Measurement Extractors. These extractors function to locate the target within the range gate and are designed to extract approximately 60 different measurements from each target. These extracted measurements are then combined with the Fine Tracker and External Information inputs listed in Tables 1 and 2 and are further processed by the Measurement Processor routines. The resulting output is a set of 15 values which will be referred to as the "target parameters" for each target.

The target parameter quantities are used directly to produce estimates of target class and target tactics each ping. As shown in Figure 1, the estimate of target class is combined with the estimate of target tactics to arrive at an evaluation of the target's threat level. The pertinent information deduced about the target (estimate of class, evaluation of threat

level, alerts to change in tactics, and the target parameter values) is then transmitted to the portion of the ACTS which generates the output display formats.

C. Classification and Threat Evaluation Outputs

The ACTS classification and threat evaluation outputs are presented to sonar, fire control, and command and control officers in the form of digital formats on computer-driven display consoles. Included on these display formats are alerts to changes in target status, values for the target parameters, a measure of confidence in the target parameters, environmental data, sonar system performance data, high-resolution displays, active and passive track histories, fire control solutions, weapons status, and automatic classification estimates from the passive subsystem. Table 3 is a summary of all the information available from these formats.

TABLE 3. ACTS DISPLAY OUTPUTS

Target class estimates	Target aspect angle
Target threat evaluation	Target wake
Alert to change in target aspect angle	Target parameter confidence
Alert to change in target depth	Environmental data
Alert to change in target speed	Sonar system data
Alert to change in target range and bearing	High-resolution range/bearing display
Target range	High-resolution range/depression angle display
Target bearing	High-resolution range/amplitude display
Target speed	Active track history
Target course	Passive track history
Target depth	Fire control solutions
Target length	Weapons status
Target depression angle	Passive classification estimate
Target maneuver rate	

IV. MEASUREMENT EXTRACTION

A. Measurement Extraction For Split-Beam Data

The primary function of the Split-Beam Measurement Extractor is to isolate target traces within the split-beam range gate data and extract measurements of the target's leading and trailing edges. At present, it is felt that these measurements can most accurately be extracted by an operator stationed at a computer-driven display console. Ideally, measurement extraction will occur once each ping for each target, the result being a set of values for each of the split-beam measurements listed in Table 4.

TABLE 4. SPLIT-BEAM MEASUREMENT EXTRACTOR OUTPUTS

- Leading edge range, initial echo
- Trailing edge range, initial echo
- Leading edge range, first multipath
- Trailing edge range, first multipath
- Leading edge range, second multipath
- Trailing edge range, second multipath
- Leading edge bearing, initial echo
- Trailing edge bearing, initial echo
- Leading edge bearing, first multipath
- Trailing edge bearing, first multipath
- Leading edge bearing, second multipath
- Trailing edge bearing, second multipath
- Leading edge depression angle, initial echo
- Trailing edge depression angle, initial echo
- Leading edge depression angle, first multipath
- Trailing edge depression angle, first multipath
- Leading edge depression angle, second multipath
- Trailing edge depression angle, second multipath
- Depression angles of 50 initial echo events
- Bearings of 50 initial echo events
- Amplitudes of 50 initial echo events
- Amplitudes of all target events
- Amplitudes of all nontarget events
- Number of target events
- Number of nontarget events
- Flags for each of the above items

A computer-generated display format is a necessity for presenting the large quantities of data involved in measurement extraction. Figure 2 is a candidate display format for this task. It simultaneously gives the operator three different representations of the data: (1) range versus bearing, (2) range versus depression angle, and (3) range versus amplitude.

The operator's initial task is to isolate the target trace(s) within the range gate by performing coarse visual correlations between the three representations of the data. Once a target trace is isolated, the operator is required to perform fine horizontal correlations to obtain estimates of the target's leading and trailing edges in range. This task is facilitated by a movable horizontal cursor which extends across all three data representations and the vertical movements of which are under operator control. The operator simply moves the horizontal cursor up and down until it lies on the best estimates for the target's leading and trailing edges based on simultaneous consideration of all three representations of the data. The operator then estimates the bearing and depression angle associated with the target's leading and trailing edges. The techniques employed here is to use a small circular indicator (ball tab) which is moved horizontally along the cursor. Thus, once the location in range of the target's leading or trailing edge is made, the operator moves the ball tab until it is superimposed on the point where the target trace and the horizontal cursor intersect. The operator then signals the computer to record the present coordinates of the ball tab. The operator repeats this process until all the leading and trailing edge range versus bearing and leading and trailing edge range versus depression angle coordinates of the target trace are entered into the computer.

The operator has the responsibility of deciding whether or not multipath returns are present. The occurrence of multipath returns will, at best, be infrequent. This is because the physical parameters of water depth, platform depth, target depth, bottom reflectivity, bottom slope, transmission depression angle, sea state, target aspect angle, and target range must all fall within certain limits for multipath returns to occur. In spite of these numerous constraints, multipath returns for submarine targets have been successfully detected in sea tests.[2] Multipath returns occur only in a bottom bounce transmission mode and originate when multiple acoustic transmission paths exist between the source and the target due to reflections from the surface. Figure 3 illustrates the three possible acoustical transmission paths. These are: (1) the initial echo: path AB-BA; (2) the first multipath: path AB-CDE or EDC-BA; and (3) the second multipath: path EDC-CDE. Target traces typifying multipath returns are shown on the measurement extraction display format of Figure 2. Note that the target trace appears three times and that the multipath returns have greater ranges than the initial echo return due to the longer multipath transmission paths which include surface reflections.

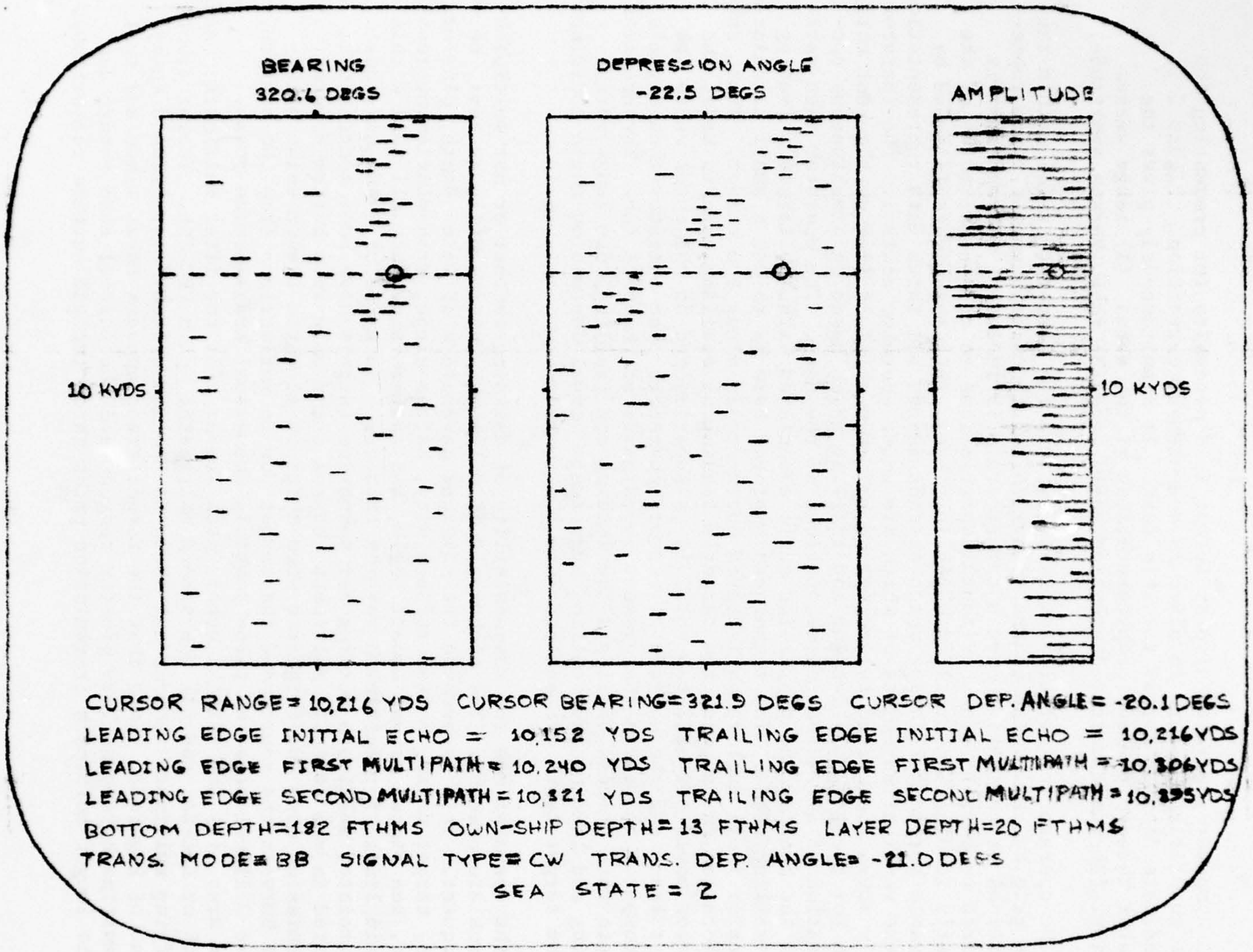

FIGURE 2. Split-Beam Measurement Extractor Display Format.

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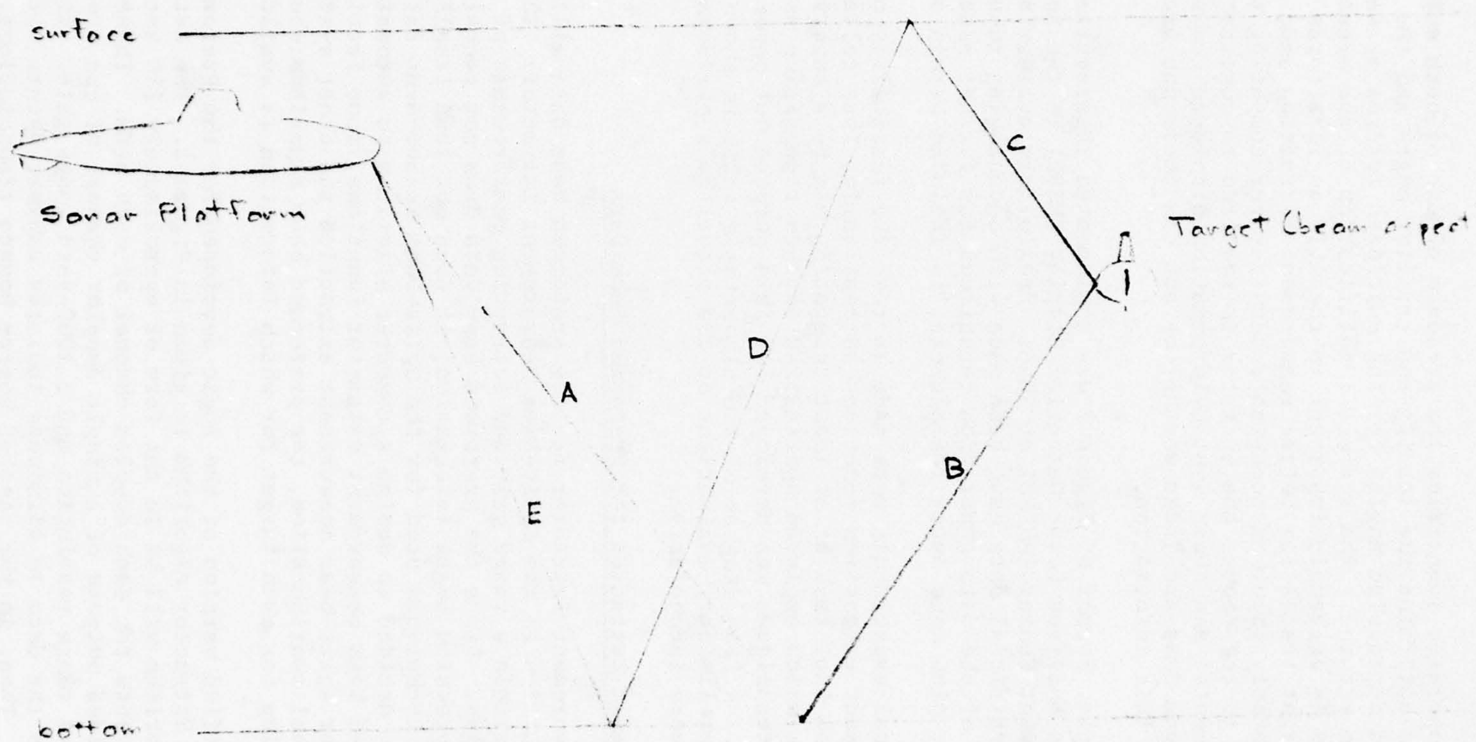


FIGURE 3. Acoustic Transmission Paths for Initial Echo and Multi-Path Echo Returns.

If the operator identifies the presence of one or both multipath returns, he must also determine the leading and trailing edges and the corresponding bearings and depression angles for the multipath returns as well as for the initial echo returns. The correct identification of the presence of multipath returns is extremely important to the ACTS as it affords the operator multiple target traces for better measurement extraction and, in addition, provides the only inputs of acceptable accuracy for computing target depth.[3] In addition to the above, the operator is required to consider continually the environmental and sonar system information displayed concurrently with the split-beam data and judge whether or not his decisions are reasonable in light of this information.

The display format of Figure 2 was implemented in essentially the form shown on the Modified Sonar Detection Display (MSDD) in the Applied Systems and Development Center (ASDEC) at NELC. Preliminary evaluations of this format on artificial data have been made with encouraging results. A description of the data generation techniques for further assessing these evaluations, plus some later refinements, is included herein as Appendix A.

Additional experiments were made to test the feasibility of performing the measurement extraction functions automatically, thus relieving the operator from that task or at least relegating him to a supervisory role. An algorithm which employed specialized pattern recognition and measurement extraction techniques was developed for this purpose but never became completely operational. A flow diagram of the algorithm's logic is shown in Figure 4. Results of preliminary evaluations of the algorithm's performance on simulated data were inconclusive.

B. <u>Measurement Extractor for Preformed Beam Data</u>

The Measurement Extractor for the preformed beam data will have essentially the same function as the Split-Beam Measurement Extractor: that of isolating the target within a range gate and extracting measurements of its leading and trailing edges. Since the preformed beam data does not contain fine bearing and fine depression angle information, it does not lend itself to the visual correlation techniques used for the Split-Beam Measurement Extractor. Therefore, it was decided to design a computer algorithm to automatically perform the preformed beam measurement extractor functions, thus freeing the sonar operators for split-beam measurement extraction and other system tasks. In an operational configuration, the preformed beam algorithm would be applied once each ping for each target for which information is available.

A simplified version of the logic developed for the Preformed Beam Measurement Extractor algorithm is given in Figure 5. The data available to this algorithm will be in the form of approximately 250 zero or nonzero amplitude events for each doppler channel of each beam. These data represent the thresholded outputs of a single doppler channel of one preformed beam having 4-yard range resolution and a 1000-yard range gate. The algorithm first preprocesses the data to eliminate isolated nonzero events with intermediate amplitudes. Then, in the case of bottom bounce transmissions, the algorithm iteratively attempts to isolate three (initial echo and both multipath) returns,

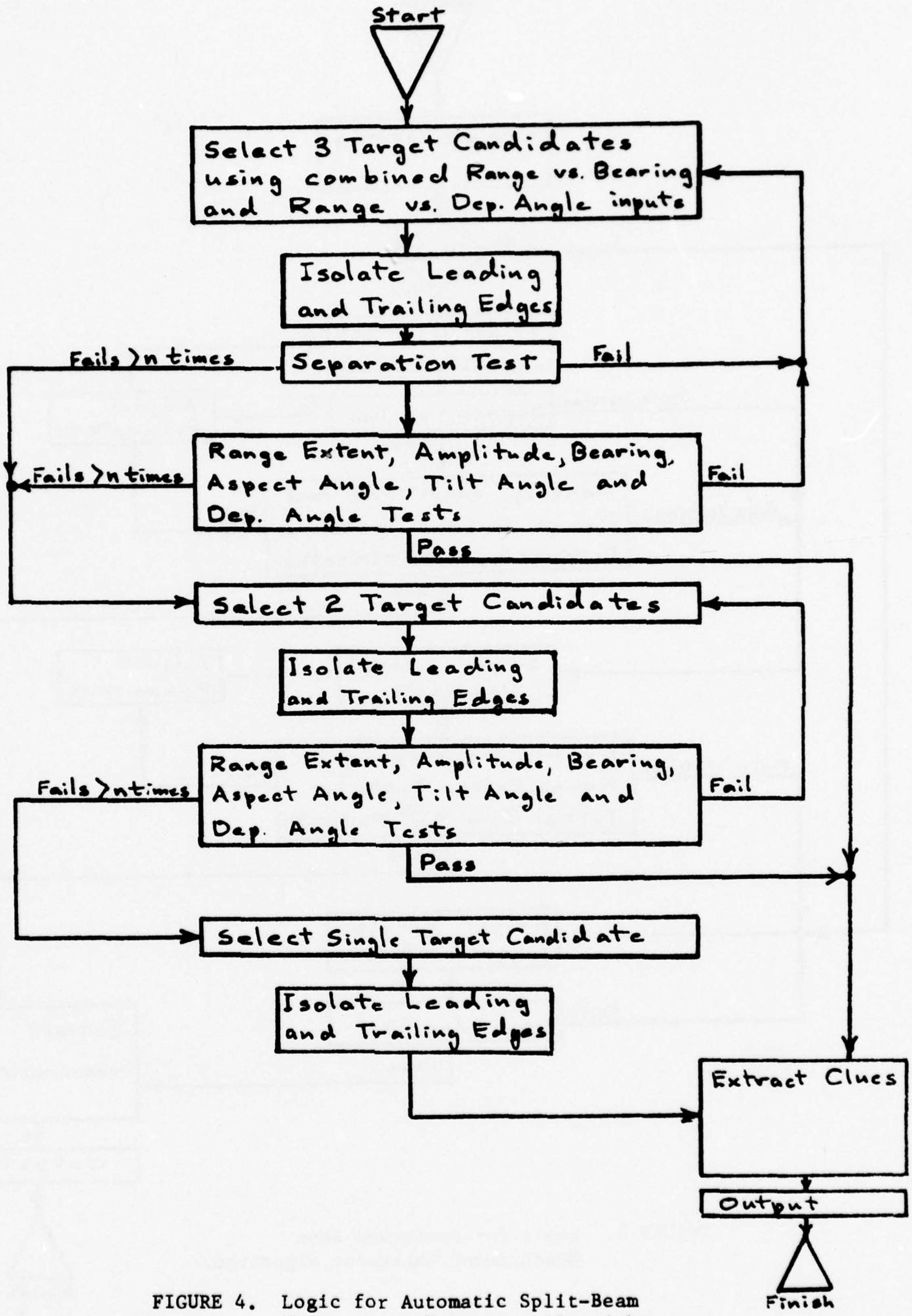


FIGURE 4. Logic for Automatic Split-Beam Measurement Extractor Algorithm.

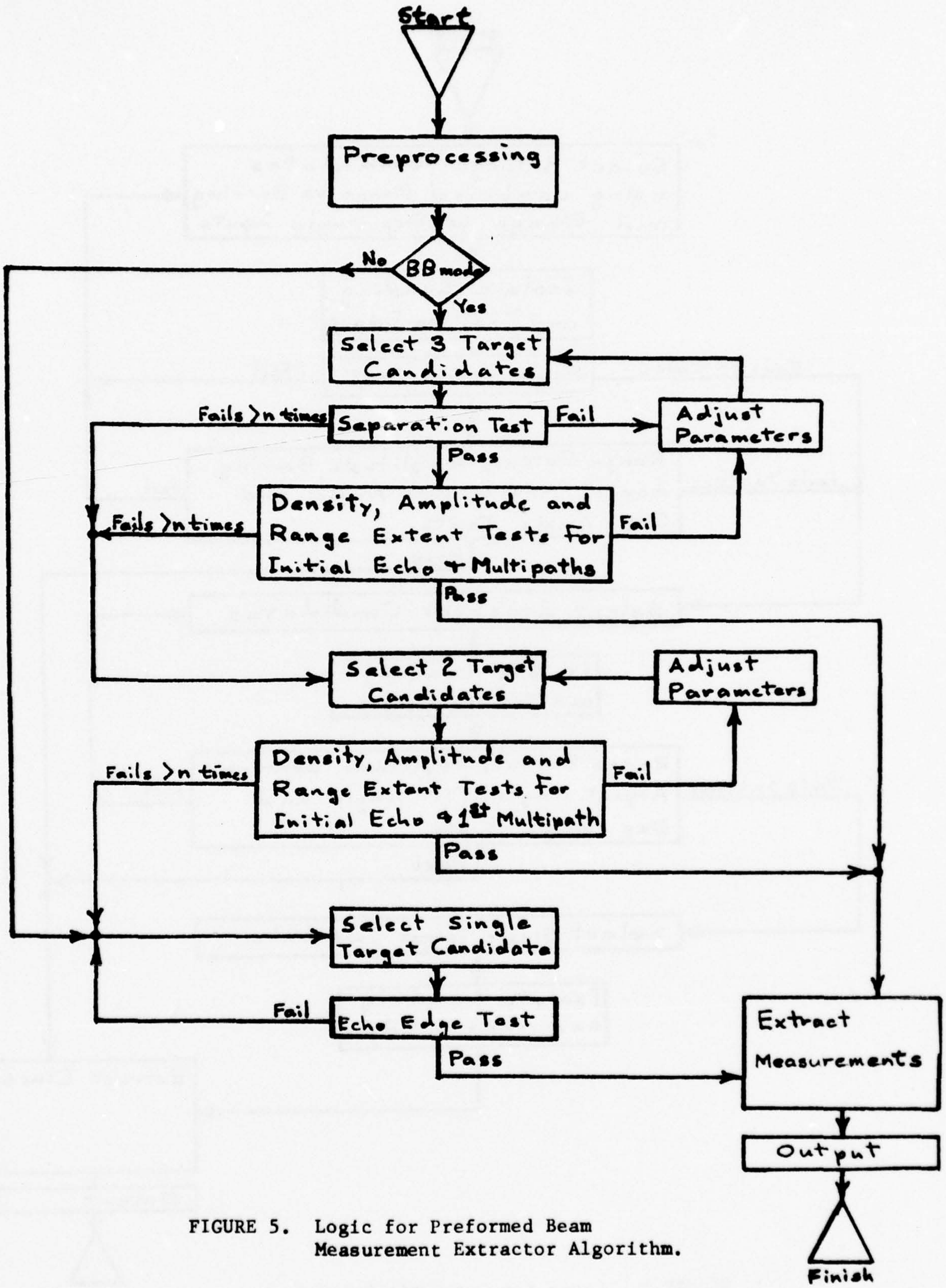


FIGURE 5. Logic for Preformed Beam Measurement Extractor Algorithm.

two (initial echo and first multipath) returns, or just a single (initial echo) return. Intertarget comparisons of average amplitude, event density, range extent, and separation distance are used to make the determination of whether multipath returns are present or not. For surface duct and convergence zone transmissions, the algorithm immediately isolates only the single best target candidate on the basis of average amplitude, event density, and range extent. Once the algorithm has isolated the target return(s), it automatically extracts values for each of the measurements listed in Table 5. These measurements are self-explanatory with the exception of the estimate of fine bearing. The computation of fine bearing estimate (±2.5) to be added to the fixed bearing of the target preformed beam is based on a best-fit approximation to the amplitude structure of the side-lobe response in the three adjacent preformed beams on left and right sides of the target preformed beam. This technique is based on the results of side-lobe structure experiments performed on the LORAD data.[4]

A preliminary evaluation of the performance of the Preformed Beam Measurement Extractor was made using artificial data. Graphs were produced showing the algorithm's performance as a function of target S/N ratio, echo length, echo separation (applicable only when one or both multipath returns were present), multipath condition, and amplitude threshold setting. A target was considered to have been isolated within acceptable limits when the algorithm's extracted values for target range within the range gate, target range extent, separation of target multipath returns (when computable) were each in error by less than 10 yards. The graphs indicated that the algorithm's performance was generally consistent over the range of parameters tried. A further explanation of the evaluation of the preformed beam measurement extractor is given in Appendix C.

TABLE 5. PREFORMED BEAM MEASUREMENT EXTRACTOR OUTPUTS

Leading edge range, initial echo

Trailing edge range, initial echo

Leading edge range, first multipath

Trailing edge range, first multipath

Leading edge range, second multipath

Trailing edge range, second multipath

Bearing of target preformed beam

Fine bearing estimate

Depression angle of target preformed beam

Number of events in each doppler channel after thresholding

Number of events (after thresholding) in the 50 yards in front of the leading edge of the initial echo in the zero doppler channel

Number of events (after thresholding) in the 50 yards behind the trailing edge of the initial echo in the zero doppler channel

Flags for the above items

V. MEASUREMENT PROCESSING

The portion of the ACTS which processes the fine tracking, split-beam and preformed beam measurements along with the various external information inputs (see Tables 1,2,4, and 5) to produce a set of "target parameters" (see Table 6) is referred to as the Measurement Processor. As with the Split-Beam and Preformed Beam Measurement Extractors, the Measurement Processor routines are invoked on a once-per-ping basis for each target. In many instances, the routines are able to compute values for a target parameter from measurements from more than one source. In the cases where valid target data are available from multiple sources, separate parameter values are computed and a weighted average is taken to determine the final value for the parameter. The weighting factors used in the averaging process will ideally be obtained from error statistics experimentally extracted from operational versions of the Fine Tracking Program and the Split-Beam and Preformed Beam Measurement Extractors. In lieu of these operationally obtained error statistics, the present version of the ACTS uses rough estimates of these error statistics. These weighting factors can be easily modified in the ACTS program as better information becomes available for the error statistics.

When multiple values for a target parameter are computed, the ACTS also computes a parameter confidence level in the interval [0 - 3]. The value of the parameter confidence level depends on the agreement (absolute value of the difference) between the two computed parameter values. If the difference between the two values for the parameter is small, the resulting confidence level is close to the maximum value of 3. Large differences produce correspondingly lower confidence levels. Of course, if the target measurements for a particular parameter calculation are not available from one of its normal sources on a given ping, the weighted averaging and confidence level calculations are not performed and the single available value is used for the target parameter.

TABLE 6. MEASUREMENT PROCESSOR OUTPUTS (TARGET PARAMETERS)

Target bearing	Target aspect angle
Target depression angle	Target depth
Horizontal target range	Target speed
Target range extent	Target inclination
Target bearing extent	Target signal-to-noise ratio
Target depression angle extent	Target wake indicator
Target length	Average parameter confidence level
	Parameter quantizations

The following paragraphs discuss each of the software routines which comprise the Measurement Processor.

A. Target Bearing

The target bearing routine computes target bearing from the Split-Beam Measurement Extractor measurements as the average of the bearings associated with the leading and trailing edges of the initial echo return. Target bearing from the Preformed Beam Measurement Extractor measurements is simply the coarse bearing (5-degree resolution) associated with the target preformed beam. However, there are occasions when the side-lobe amplitude structure of the preformed beams which are horizonally adjacent to the target preformed beam will permit estimation of fine target bearing. If fine bearing is computed, the target bearing routine will treat it as a refinement to the coarse bearing measurement normally available from the target preformed beam. The final target bearing parameter value is the weighted average of the separate target bearings computed from the Split-Beam and Preformed Beam Measurement Extractor measurements.

B. Target Depression Angle

The computations of target depression angle parameter are analogous to those performed for the target bearing parameter except that depression angle versus range data are being dealt with rather than bearing versus range data. The only difference between the two routines is that in the depression angle routine no attempt is made to extract an estimate of fine depression angle from the side-lobe structure of vertically adjacent preformed beams. The final value for the depression angle parameter is a weighted average of the target depression angles which were determined separately from the two sets of Measurement Extractor measurements.

C. Horizontal Target Range

Target range is determined by first computing the range from the center of the range gate to the midpoint between the leading edge and trailing edge of the initial echo return. This value is then added to the range to the center of the range gate. Calculations identical to those just described are done separately for the measurements from the Split-Beam and Preformed Beam Measurement Extractors. A weighted average of the two values for target range is then taken to produce the target range parameter.

The computed value for target range represents the desired horizontal target range only in the case of surface duct transmissions. For bottom bounce, the computed target range actually represents the slant range of the acoustic transmission path and must be converted to horizontal target range by equation 1.

$$\text{Horizontal Target Range} = (\text{Slant Range})(\sin\theta) \qquad (1)$$

where θ is the transmission depression angle. For convergence zone transmission, the computed target range must also be adjusted to compensate for the length of the acoustic path as compared to the target's actual horizontal range. No formal relationship for the adjustments for convergence zone transmission has

yet been formulated, but it is known that it will depend on various environmental and system parameters including transmission depression angle, water depth, platform depth, water temperature and salinity.

D. Target Range, Bearing, and Depression Angle Extents

These routines compute separate values for the target's extent in range, bearing, and depression angle. The measurements required for computing range extent are available from both the Split-Beam and Preformed Beam Measurement Extractors. In both cases, range extent is computed as the magnitude of the difference in range between the leading and trailing edges of the initial echo return. If multipath returns are detected in either Measurement Extractor, the range extents of the multipath echoes are also computed and are averaged with those of the initial echo to produce the range extent. A weighted average of the range extents computed from each set of Measurement Extractor measurements is then taken to produce the final range extent parameter value.

The computation of bearing and depression angle extents can only be made from the fine bearing and depression angle information available in the Split-Beam Measurement Extractor data. Here, the magnitudes of the differences in bearing and depression angle for the leading and trailing edges of the initial echo return are computed and then averaged with the extents of any detected multipath returns. The bearing and depression angle extents are then converted from units of degrees (radians) into yards. The relationship used for this conversion is necessarily a function of target range and is given as equation 2:

$$\text{Bearing or Dep.Angle Extent} = [\text{Target Range(yds)}][\text{Bearing or Dep.Angle Extent(radians)}] \qquad (2)$$

E. Target Length

The target length routine computes a value in yards for actual target length. As computed, this value is independent of the visually distorting effects of target aspect angle, inclination, and range that the present-day sonar operator must contend with. Calculation of target length can be made only if processed values for target range extent, bearing extent and depression angle extent are available. The relationship used to compute target length is given below:

$$\text{Target Length} = \sqrt{(\text{Range Extent})^2+(\text{Bearing Extent})^2+(\text{Dep.Angle Extent})^2} \qquad (3)$$

where the range, bearing, and depression angle extents are in units of yards.

F. Target Aspect Angle

Information useful in computing the target's current aspect angle is available from two sources: The estimate of target course from the fine

tracking program and the processed target range and bearing extents from Split-Beam Measurement Extractor measurements. The fine tracking program's estimate of target course is assumed to be based on a polar coordinate system which is centered on the transmitting sonar's platform (own-ship) with zero degrees corresponding to the direction of the platform's forward motion. In this coordinate system, knowledge of the target is complete if its range, bearing and course are known.

The calculation of target aspect angle from the Split-Beam Measurement Extractor data consists of using the previously computed target range extent and bearing extent values and is shown in equation 4:

$$\text{Target Aspect Angle} = \tan^{-1}\left(\frac{\text{Bearing Extent}}{\text{Range Extent}}\right) \qquad (4)$$

This computation of target aspect angle is made from a different polar coordinate system from that used by the fine tracking program. This system is centered on the target with the zero degree direction being superimposed on own-ship's bearing for the target. Figure 6 illustrates how the same target appears on both coordinate systems. The relationship which must be used to convert target course from the fine tracking program into a value which can be averaged with the aspect angle computed in Equation 4 is given below:

$$\text{Target Aspect Angle} = 180^{\circ} + \text{Target Course} - \text{Target Bearing} \qquad (5)$$

G. Target Depth

The target depth parameter is extremely valuable in performing meaningful manual or automatic target classification and threat evaluation. Unfortunately, determination of target depth is among the most difficult of the target parameter values to obtain. Two approaches for extracting target depth information have been investigated. Both require a bottom bounce mode of transmission before any estimate of target depth can be made. The first technique attempts to compute target depth from knowledge of length of transmission path (slant range), transmission depression angle (θ), and bottom depth. The relationship used is the following equation:

$$\text{Target Depth} = 2(\text{Bottom Depth}) - (\text{Slant Range})(\sin\theta) \qquad (6)$$

It is apparent from this equation that the desired depth information must be obtained as the difference between two large numbers, neither of which is known very accurately.[5] A cursory analysis of this technique has indicated that the expected errors in the knowledge of the three variables involved make this method of little value. For this reason, this technique was not implemented as one the ACTS Measurement Processor routines.

The second and preferred method of computing target depth depends on the relatively rare occurrence and detection of multipath echo returns.

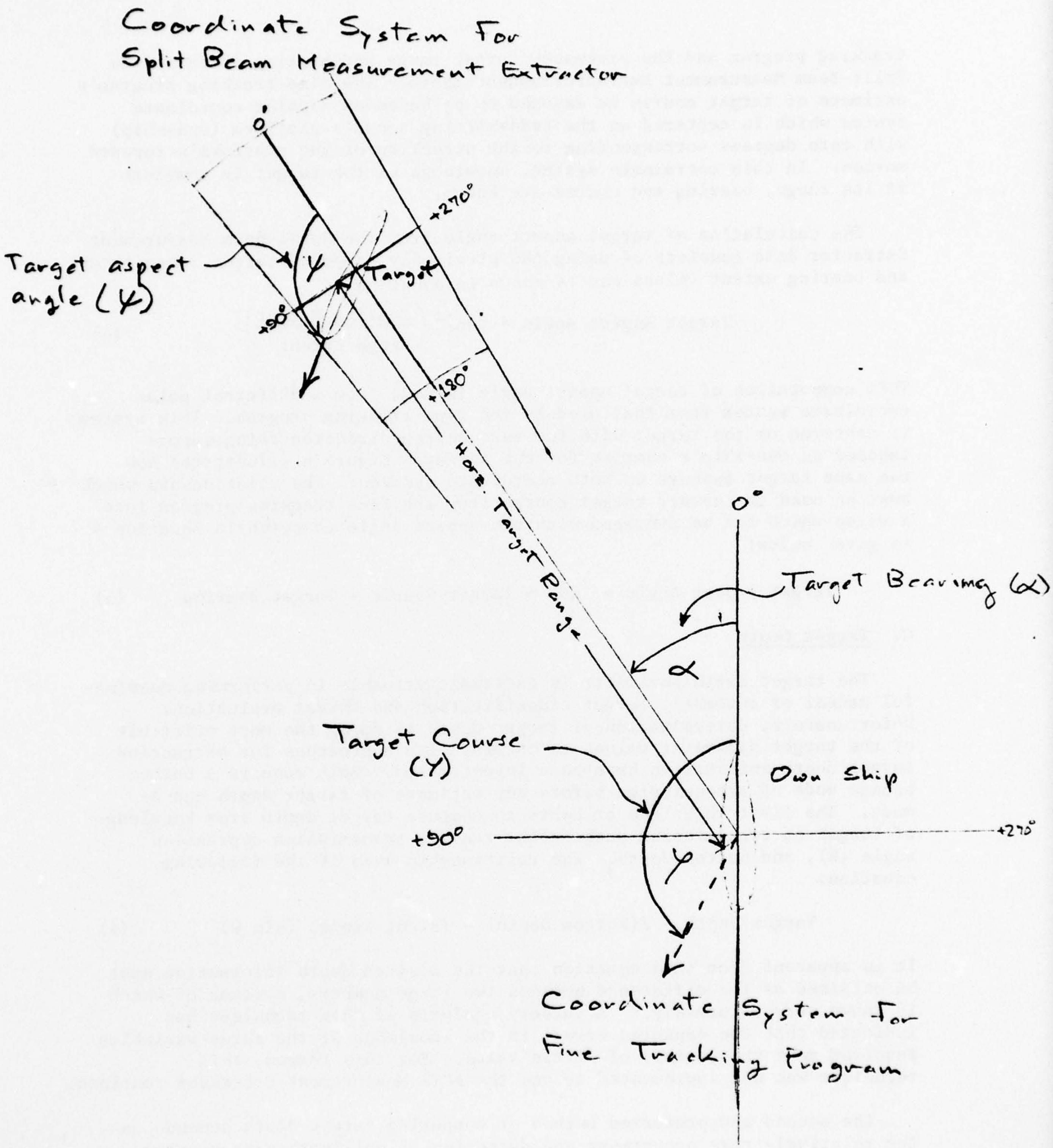


FIGURE 6. Coordinate Systems for Split Beam Measurement Extractor and Fine Tracking Program.

When multipath returns are detected, in either the Split-Beam or the Preformed Beam Measurement Extractors, the target depth routine computes the magnitude of the average of the differences in range between the centers of the initial echo and the first multipath echo return and between the centers of the first and second multipath echo returns. This average multipath separation distance is used directly to compute a value for target depth by evaluating equation 7:

$$\text{Target Depth} = \frac{\text{Multipath separation Distance}}{2 \sin \theta} \tag{7}$$

Where θ is again the transmission depression angle. This latter technique for computing target depth does not have the potential for the large errors of the previously described technique and is implemented in the ACTS target depth routine.

In the event that multipath returns are not present or are present but not detected, a technique has been incorporated into the ACTS which will give an extremely coarse evaluation of whether the target is on the surface, submerged, or if no determination can be made. From knowledge of the bottom depth, own-ship's depth, and the transmission depression angle, a rough estimate of the maximum possible slant range can be made. If the slant range to the target is less than one-half of the maximum slant range, then the target is assumed to be submerged. However, if the target's slant range is between one-half and five-fourths of the maximum slant range, a surface or subsurface determination cannot safely be made. Finally, if the target's slant range is greater than five-fourths of the maximum, then the target is assumed to be on the surface.

H. Target Speed

The calculation of target speed requires a measurement of target doppler from the fine tracking program and the previously processed value for target aspect angle. When both are available, target speed is computed as

$$\text{Target Speed} = \frac{\text{Target Doppler}}{\cos\,(\text{Target Aspect Angle})} \tag{8}$$

The final value for the target speed parameter is the weighted average of the target speed computed in equation 8 and separate target speed measurement from the fine tracking program.

The two target speed values obtained from equation 8 and the fine tracking program are compared to permit the calculation of a target speed confidence level. However, this confidence level is then averaged with an additional confidence level which is based on a measurement of the target doppler ratio within the preformed beam data. This target doppler ratio confidence level is the number of samples exceeding the amplitude threshold on the preformed beam doppler channel corresponding to the doppler measurement from the fine tracking program divided by the total number of

thresholded samples in all of the target preformed beam's doppler channels.

I. Target Inclination

The target inclination parameter measures the inclination of the major axis of the target with respect to the horizontal (surface of the water). The following processed information must be available for the inclination parameter to be computed: Target depression angle extent, bearing extent, range extent, and target depression angle. The relationship between these variables is as follows:

$$\text{Target Inclination} = \tan^{-1}\left(\frac{\text{Depression Angle Extent}}{\sqrt{(\text{Range Extent})^2+(\text{Bearing Extent})^2}}\right) \tag{9}$$

J. Target Signal-to-Noise Ratio

Amplitude information available to the ACTS is derived from the split-beam data. As previously discussed, amplitude information is extracted for each 4-yard range resolution element within the range gate. As the location of the range resolution elements which are associated with the target initial echo and multipath returns are determined, the average of the target amplitudes is taken along with the average amplitude of the remaining nontarget amplitudes. The value for the target signal-to-noise ratio parameter is then computed by applying equation 10:

$$\text{Signal-to-Noise Ratio} = 20\log_{10}\frac{\text{Avg. Amplitude of Target Elements}}{\text{Avg. Amplitude of Nontarget Elements}} \tag{10}$$

K. *Target Wake Indicator*

The presence of target wake is characterized by a high concentration of samples in the target preformed beam which exceeded the threshold in the zero or near-zero doppler channels. This is in addition to the samples normally detected in the higher doppler channel(s) due to the target's motion. The procedure used to determine the presence of target wake separately sums the number of samples which exceeded the amplitude threshold in the zero doppler channel for the 50 yards in front of the leading edge (NELZ) and the 50 yards behind the trailing edge (NETZ) of the target's initial echo return. If the target is closing with respect to own-ship and creating a wake, the ratio of NETZ/NELZ may be large enough to be thresholded and thus indicate the presence of target wake. However, if the target is opening with a wake, the reverse ratio of NELZ/NETZ is thresholded. For a moving target which is not creating a wake, both ratios should be close to unity and would not pass a wake indicator threshold.

L. Parameter Confidence Level

This routine is designed to produce a single overall parameter confidence level which can be assigned to the current set of target parameter values for each target. This overall parameter confidence level is also in the interval [0-3] and is computed as the average of the individual

confidence levels for which sufficient data were available to permit computation. Included in the confidence levels averaged to produce the overall parameter confidence level is the target track confidence level from the fine tracking program.

M. Parameter Quantization

The final Measurement Processor routine is designed to quantize each of the target parameter and confidence level values into finite sets of elements. Each element of these sets has a value of either 0 or 1 and corresponds to a fixed interval within the acceptable range of values for the parameter and confidence level values. The quantization process simply sets the proper element of each set to 1 while leaving the remaining elements equal to 0. This procedure is necessary to use the processed target parameter and confidence level values in the structure of the logic equations which comprise the Target Class, Target Tactics, and Target Threat Level Estimators.

VI. ESTIMATION OF TARGET CLASS, TACTICS, AND THREAT LEVEL

The ultimate goal of the ACTS is to provide the sonar classification operator with automatic estimates of target class, tactics and threat level each ping for every target for which information is currently available. These estimates give the operator a rapid and comprehensive analysis of the processed input data and are intended to aid him in arriving at target classification and threat evaluation decisions. It must be kept in mind, however, that automatic estimates of target class, tactics and threat level are nothing more than the results of a computer's objective analysis of a relatively small set of inputs. The computer cannot accurately extrapolate or draw logical conclusions from the input data; the responsibility for these tasks must remain with the classification operator. The only instance when the ACTS will appear to make absolute target classification and threat evaluation decisions is when intelligence information such as IFF is known for a target. In this case, the routines which estimate target class, tactics and threat level are simply by-passed. The target class and threat level which are forwarded to the classification operator are obtained directly from the intelligence data and are not processed outputs from the ACTS.

In the normal mode of operation, when intelligence information is not present, the technique used to evaluate the processed target parameter values and arrive at the desired estimates is based on rapid computer evaluation of Boolean logic equations. Each equation defines a unique target class, tactics or threat level category in terms of subsets of the quantized target parameters. If at least one target parameter in each of the target parameter subsets comprising a category description is equal to 1, then that category is assigned a value of 1. This is equivalent, in the Boolean sense, to performing the OR operation (+) on the elements within each parameter subset followed by application of the AND operation (.) to all of the evaluated subsets. The categories which are set equal to 1 by this process are selected as the ACTS estimates of target class, tactics and threat level. The remainder of this section deals with the details of the implementation of the logic equations in the class, tactics, and threat level estimator routines.

A. Target Class Estimator

The Target Class Estimator routine consists of a set of logic equations which describe, in terms of the subsets of the target parameters which apply, six target class categories. The defining logic equations for these class categories are given in Appendix D. The categories themselves are listed as Table 7.

TABLE 7. TARGET CLASS CATEGORIES

TC[1]:	Submarine
TC[2]:	Surface Ship
TC[3]:	Torpedo
TC[4]:	Missile
TC[5]:	Countermeasure
TC[6]:	Other (schools of fish, seamounts, reverberation, etc.)

Ideally, the function of the Class Estimator routine is to select the target class category which is uniquely described by the subset of quantized target parameter inputs. Realistically, it must be acknowledged that a sufficient number of target parameter inputs will not always be available to uniquely determine a class category for every target each ping. Depending on which target parameters are missing, this may result in the selection of more than one class category for the target. For example, if a value for the target depth parameter is missing, the Target Class Estimator routine cannot easily distinguish between the categories for submarine and surface ship since the remaining pertinent parameters may be the same for both categories. In response to the operational requirement of providing target class estimates even when only partial information is available, the Class Estimator logic has been designed to select at all times all class categories described by the partial list of parameters and to compute a confidence level for each category selected. The confidence levels are computed as the average of the processed target parameter confidence levels used to select the class categories. The class categories with the highest average confidence levels are selected and ranked in order of confidence level. The final output of the Target Class Estimator is a list of no more than the three highest ranking target class categories and their confidence levels.

TABLE 8. SINGLE-PING TARGET TACTICS CATEGORIES

Category	Range	Aspect Angle	Depth	Speed
TT[1]	Close	Closing	Shallow	Fast
TT[2]	Close	Closing	Shallow	Slow
TT[3]	Close	Closing	Deep	Fast
TT[4]	Close	Closing	Deep	Slow
TT[5]	Close	Holding range	Shallow	Fast
TT[6]	Close	Holding range	Shallow	Slow
TT[7]	Close	Holding range	Deep	Fast
TT[8]	Close	Holding range	Deep	Slow
TT[9]	Close	Opening		Fast
TT[10]	Close	Opening		Slow
TT[11]	Intermediate	Closing	Shallow	Fast
TT[12]	Intermediate	Closing	Shallow	Slow
TT[13]	Intermediate	Closing	Deep	Fast
TT[14]	Intermediate	Closing	Deep	Slow
TT[15]	Intermediate	Holding range	Shallow	Fast
TT[16]	Intermediate	Holding range	Shallow	Slow
TT[17]	Intermediate	Holding range	Deep	Fast
TT[18]	Intermediate	Holding range	Deep	Slow
TT[19]	Intermediate	Opening		Fast
TT[20]	Intermediate	Opening		Slow
TT[21]	Long			

B. Target Tactics Estimator

The Target Tactics Estimator contains 34 different target tactics categories. These are divided into three different groups: single-ping, 2-ping history, and 6-ping history. A description of the single-ping tactics categories is given in Table 8. The corresponding single-ping logic equations are contained in Appendix E.

Multiple-ping target tactics estimation requires the storage of data from previous pings for each target. For example, the calculation of target maneuver rate (TT[34]) for each target requires that the current 6-ping history of the target be available so that equation 11 can be evaluated on a once-per-ping basis.

$$TMR = \frac{\sum_{i=2}^{6} \text{Maneuver Indicator}}{\sum_{i=1}^{6} (TR_{i-1})^2 + (TR_i)^2 - 2(TR_{i-1})(TR_i)\cos[(TB_{i-1})-(TB_i)]} \tag{11}$$

where: TR = TARGET RANGE and TB = TARGET BEARING

Evaluation of equation 11 requires that each target in the system be assigned an identifying number. This number will be used for indexing storage lists and will be reassigned to a new target when the old one is lost or intentionally disengaged. The complete descriptions and definitions of all the 2-ping history and 6-ping history target tactics categories are contained in Tables 9 and 10.

TABLE 9. TARGET TACTICS CATEGORIES FOR 2-PING HISTORY

TT[22]:	Change in Course (Aspect Angle) ≥ |30°|	TT[22]=1
	Change in Course (Aspect Angle) < |30°| or not computable,	TT[22]=0
TT[23]:	Change in Depth ≥ |10 Fathoms|	TT[23]=1
	Change in Depth < |10 Fathoms| or not computable,	TT[23]=0
TT[24]:	Change in Speed ≥ | 15 knots|	TT[24]=1
	Change in Speed < | 15 knots| or not computable,	TT[24]=0
TT[25]:	Change in Position (Range, Bearing) ≥ |250 yds|	TT[25]=1
	Change in Position (Range, Bearing) < |250 yds| or not computable	TT[25]=0

TABLE 10. TARGET TACTICS CATEGORIES FOR 6-PING HISTORY

TT[26]:	Monotonic increase in range	TT[26]=3
	Net increase$\{\text{range}_{\text{ping 1}} < \text{range}_{\text{pings 2-5}} < \text{range}_{\text{ping 6}}\}$	TT[26]=2
	Net increase$\{\text{range}_{\text{ping 1}} < \text{range}_{\text{ping 6}}\}$	TT[26]=1
	Not computable	TT[26]=0
TT[27]:	Monotonic decrease in range	TT[27]=3
	Net decrease$\{\text{range}_{\text{ping 1}} > \text{range}_{\text{ping 2-5}} > \text{range}_{\text{ping 6}}\}$	TT[27]=2
	Net decrease$\{\text{range}_{\text{ping 1}} > \text{range}_{\text{ping 6}}\}$	TT[27]=1
	Not computable	TT[7]=0
TT[28]:	Maintaining range within $\lvert 100 \text{ yds} \rvert$	TT[28]=3
	Maintaining range within $\lvert 200 \text{ yds} \rvert$	TT[28]=2
	Maintaining range within $\lvert 300 \text{ yds} \rvert$	TT[28]=1
	Not computable	TT[28]=0
TT[29]:	Monotonic increase in speed	TT[29]=3
	Net increase$\{\text{speed}_{\text{ping 1}} < \text{speed}_{\text{ping 2-5}} < \text{speed}_{\text{ping 6}}\}$	TT[29]=2
	Net increase$\{\text{speed}_{\text{ping 1}} < \text{speed}_{\text{ping 6}}\}$	TT[29]=1
	Not computable	TT[29]=0
TT[30]:	Monotonic decrease in speed	TT[30]=3
	Net decrease$\{\text{speed}_{\text{ping 1}} > \text{speed}_{\text{ping 2-5}} > \text{speed}_{\text{ping 6}}\}$	TT[30]=2
	Net decrease$\{\text{speed}_{\text{ping 1}} > \text{speed}_{\text{ping 6}}\}$	TT[30]=1
	Not computable	TT[30]=0
TT[31]:	Monotonic change in course (aspect angle)	TT[31]=3
	Net change $\{\text{aspect angle}_{\text{ping 1}} \lessgtr \text{aspect angle}_{\text{pings2-5}} \lessgtr \text{aspect angle}_{\text{ping 6}}\}$	TT[31]=2
	Net change $\{\text{aspect angle}_{\text{ping 1}} \lessgtr \text{aspect angle}_{\text{ping 6}}\}$	TT[31]=1
	Not computable	TT[31]=0

NOTE: $\{A \lessgtr B \lessgtr C\} \Rightarrow \{A<B<C \text{ } \underline{\text{or}} \text{ } A>B>C\}$

CONTINUED

TABLE 10. TARGET TACTICS CATEGORIES FOR 6-PING HISTORY (CON'T)

TT[32]:	Monotonic increase in depth	TT[32]=3
	Net increase $\{depth_{ping\ 1} < depth_{pings\ 2\text{-}5} < depth_{ping\ 6}\}$	TT[32]=2
	Net increase $\{depth_{ping\ 1} < depth_{ping\ 6}\}$	TT[32]=1
	Not computable	TT[32]=0
TT[33]:	Monotonic decrease in depth	TT[33]=3
	Net decrease $\{depth_{ping\ 1} > depth_{pings\ 2\text{-}5} > depth_{ping\ 6}\}$	TT[33]=2
	Net decrease $\{depth_{ping\ 1} > depth_{ping\ 6}\}$	TT[33]=1
	Not computable	TT[33]=0
TT[34]:	Target maneuver rate = high	TT[34]=3
	Target maneuver rate = intermediate	TT[34]=2
	Target maneuver rate = low	TT[34]=1
	Not computable	TT[34]=0

As is the case with the target class categories, more than one target tactics category may simultaneously have a value of 1. This is due both to the partial information problem and to the fact that it will often be possible to make multiple-ping tactics estimates along with the single-ping estimates which are updated each ping.

C. Target Threat Level Estimator

The ACTS evaluation of potential threat to own-ship posed by a target is based on the estimates of the target's actions (tactics estimate) and of its identity (class estimate). As with the Target Class and Tactics Estimators, a system of logic equations is used to select one or more target threat level categories. The identifiable target threat level categories are listed in Table 11 and the defining logic equations are contained in Appendix F.

TABLE 11. TARGET THREAT LEVEL CATEGORIES

TTL[1]:	High
TTL[2]:	Intermediate
TTL[3]:	Low
TTL[4]:	None
TTL[5]:	Unknown

With the acknowledged possibility of selecting multiple-target class and tactics categories, it does not seem surprising that the selection of more than one target threat level categories can result. The procedure used in this event is for the Target Threat Level Estimator routine to forward to the sonar classification operator only the single-threat level estimate which corresponds to the highest threat level of the categories selected.

VII. CLASSIFICATION AND THREAT EVALUATION DISPLAY FORMATS

The treatment of the man-machine interface is critical to the operational effectiveness of any complex tactical data handling system. This is especially true with the ACTS where the computer and the sonar classification operator work in parallel to achieve the same goals. The ACTS man-machine interface consists of operator-selectable digital display formats displayed on multiple-mode display consoles which are directly driven by the DPC computer(s).

Three candidate ACTS classification and threat evaluation display formats were designed and implemented on the Modified Sonar Detection Display (MSDD) in the ASDEC area. Also implemented on this display device was the Split-Beam Measurement Extractor display format described in Section IV (see Figure 2).

The three candidate ACTS classification and threat evaluation display formats are designed for use in typical operational situations where operator-aided target classification and threat evaluation is required. The first of these formats is intended for use when a contact with a passively tracked target has been lost and the target is to be reacquired by going into an active mode. The second format logically evolves from the first and displays only the active track history of the target. The final format combines a summary of the active and passive classification estimates with tactical command and control information and fire control solutions. The important common feature of these three formats is that, in addition to the information local to each format, they all continuously display the current estimates of target class and threat level, numerical values for each of the computed target parameters, expanded area presentations of the targets as they appeared on the Split-Beam Measurement Extractor display format, and operator alerts to changes in the target's depth, speed, aspect angle and position. Thus, the operator at all times has this information available, and he may accept or reject the automatic estimates of target class and threat level after analyzing the computed target parameter values and the information which is local to his display format.

To gain insight into the effectiveness of the ACTS classification and threat evaluation display formats in an operational situation, an artificial 10-ping target encounter was generated and the results displayed on the MSDD. A description of the target encounter and photographs of the three display formats for each of the 10-pings are contained in Appendix G.

The following paragraphs are a more detailed discussion of the three candidate ACTS classification and threat evaluation display formats.

A. Passive/Active Track History Format

The ability to simultaneously display both active and passive data requires that a display device be used which is capable of generating a multi-brightness level raster (for passive data) along with a complete set of digital symbols (for active data). The Multi-Mode Display System (MMDS), which was not available when this work was done, is capable of generating such a passive/active Track History format. Figure 7 represents a rough approximation of how such a format might appear during an operational situation. The format of Figure 7 was implemented on the digital MSDD in ASDEC. Unfortunately, hardware limitations severely restricted the simulation of the passive data raster.

The coordinates for the passive/active trade history format are the familiar ones of time versus bearing. The situation portrayed in Figure 7 is the case where contact with a passively tracked target has been lost. Note that the bearing of last contact is indicated along the bottom of the display. Six active pings have been transmitted since the target was re-acquired actively. The purpose of combining the active and passive track histories in this manner is to assist the operator in rapidly determining that the active track is a logical extension of the passive track history, and, therefore, that the same target has been reacquired. Also, note that in this case the operator has selected to view the expanded area display of the target (upper left-hand corner of Figure 7) in the range-versus-amplitude representation from the Split-Beam Measurement Extractor display format. Of course, the operator can at any time select expanded areas about the target in any of the three representations; i.e., range versus bearing, range versus depression angle, and range versus amplitude. In addition, certain of the 2-ping target tactics categories which indicate significant ping-to-ping changes in target depth, speed, aspect angle, and position are being displayed as alerts to the operator.

Also, the automatic ACTS estimates of target class and threat level are displayed in the lower left-hand corner of Figure 7. The threat level estimate is displayed as a single word describing the threat level category selected; i.e., high (flashing), intermediate, low, none or unknown. The ranked list of the three (or fewer) target class estimates is displayed along with horizontal line segments whose lengths are proportional to the confidence levels of the target class categories. The line segments are designed to give the operator a rapid, graphic presentation of the relative confidence in each of the ACTS estimates of target class. The operator is also given pertinent environmental and sonar system data along the bottom of the format.

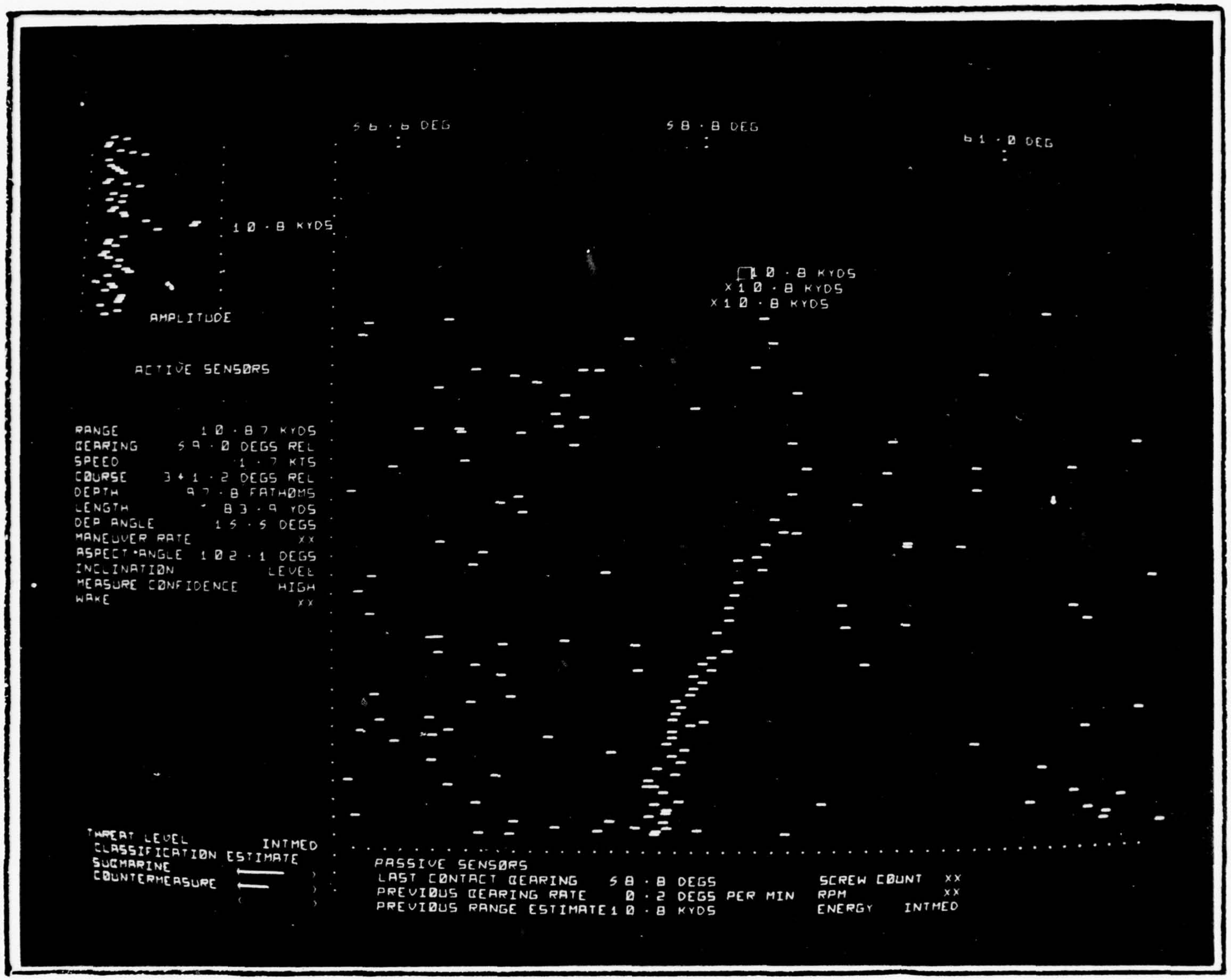


FIGURE 7. Passive/Active Track History Display Format

From this format the operator may decide that he has acquired sufficient information to make his classification and threat evaluation decisions. If this is not the case, he may choose to let the passive/active track history continue to build up, or select the format which displays only the active track history.

B. Active Track History Format

This format is intended for use when only an active history of the track is available or when the passive history is no longer considered to be of importance. The coordinates of the active track history format are horizontal range versus bearing. The candidate active track history format is shown in Figure 8. The situation depicted in this figure is that of a maneuvering target which has been tracked actively for six pings.

The operator's responsibility when viewing an active track history format is to combine the automatic ACTS estimates of target class and threat level and the system, the environmental and intelligence information inputs with his analysis of the target's active track history before arriving at his final target classification and threat evaluation decisions.

C. Command and Control/Fire Control Format

The third classification and threat evaluation format is essentially a summary format. A candidate command and control fire control format is shown in Figure 9. This format contains the pertinent ACTS data on the left-hand side of the display (estimates of class and threat level, target parameter values, operator alerts, expanded area displays) and an equivalent but necessarily different set of classification data from an assumed automatic passive classification subsystem on the right-hand side.

The center display is a tactical range versus bearing presentation which shows the relative positions of own-ship (center, near bottom), the target of current interest (center, two-thirds of the way up), and other friendly, hostile and unidentified vessels in the area. In addition, precomputed fire control solutions are superimposed on the center display and are supplemented by weapon counts and firing status information (center, bottom).

Thus, this display format provides the operator with a comparative summary of the automatic active and passive classification estimates, a range-versus-bearing display of the tactical situation, and precomputed fire control solutions. It then becomes the responsibility of the highest ranking officer in the sonar and fire control area to prudently use this and other information made available to him and make the final high-level target classification and fire control decisions.

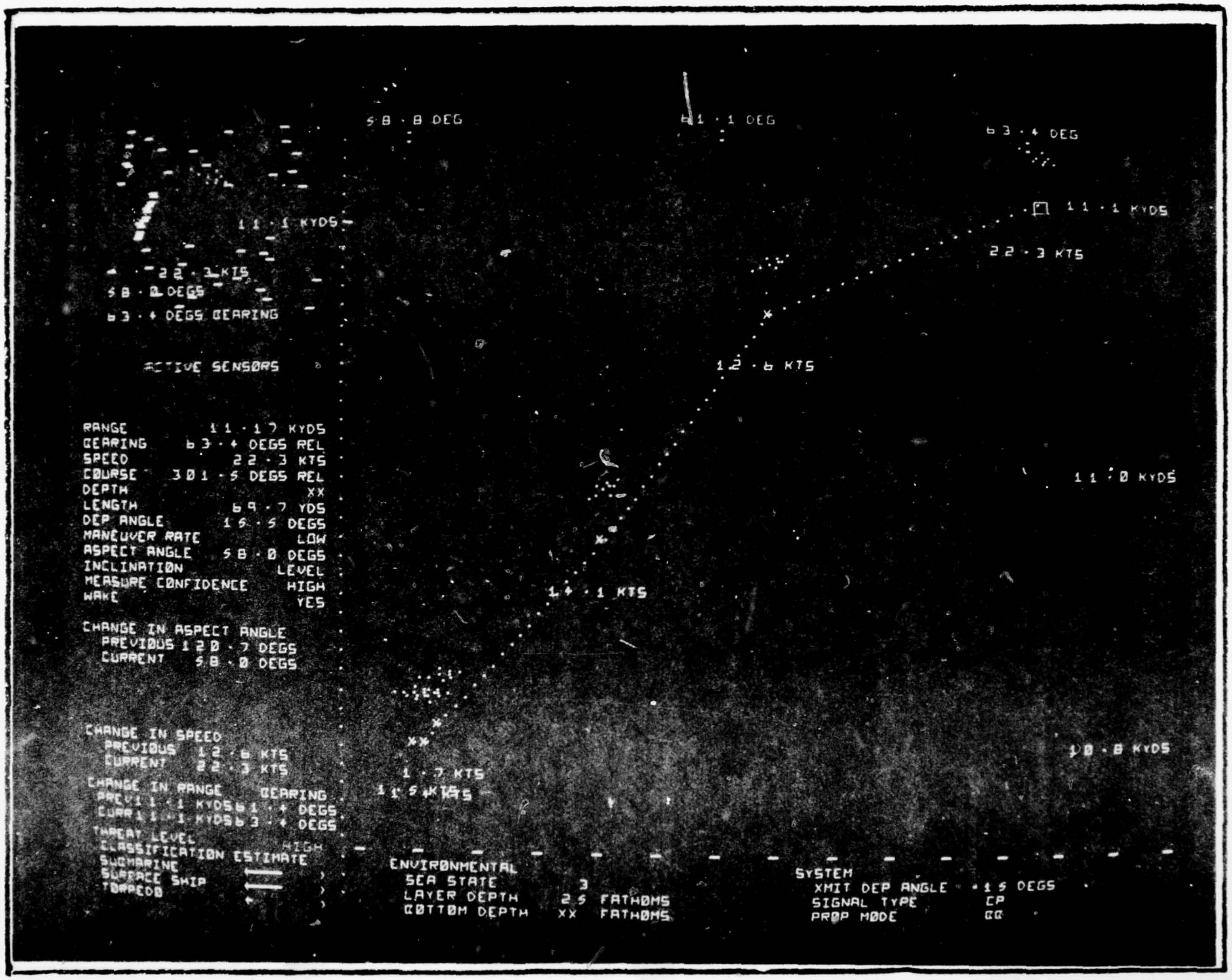


FIGURE 8. Active Track History Display Format

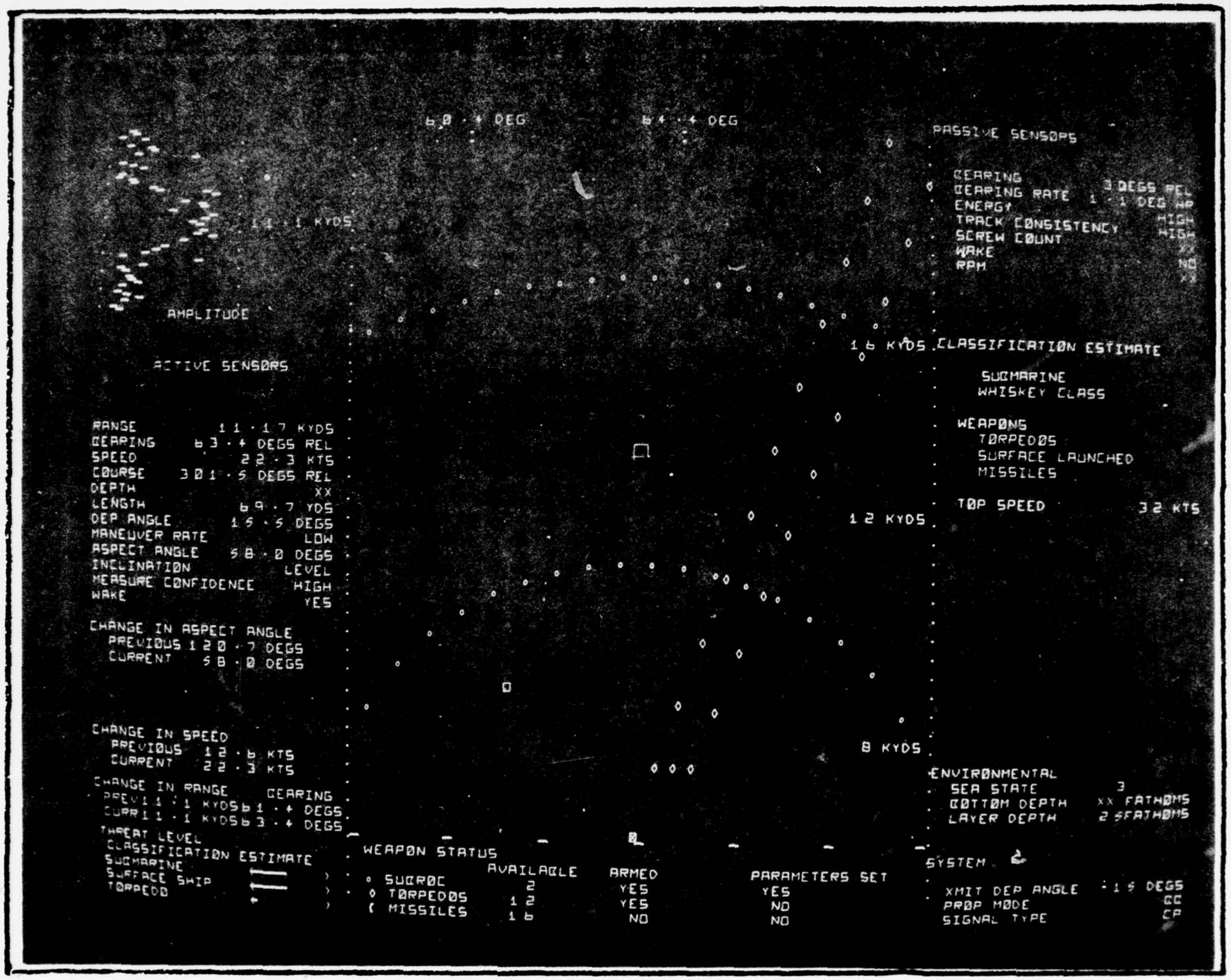


Figure 9. Command and Control/Fire Control Display Format

VIII. CONCLUSIONS AND RECOMMENDATIONS

The primary objective of the effort expended on the ACTS was to demonstrate the feasibility of incorporating a computer-assisted classification and threat evaluation subsystem into the design of an advanced submarine or surface ship sonar system.

As pointed out earlier, the decision-making structure of the ACTS is non-adaptive or deterministic and does not require iterative parameter adjustments as a result of a training or updating process. If it is determined an ACTS parameter needs adjustment, however, that parameter may be altered by simple changes to the computer programs. Also, alterations to the ACTS logic equation can be made by more complex but straightforward software modifications.

Suggested recommendations for further development and refinement of the ACTS include:

1. Implementation of the ACTS routines as part of a complete sonar data processing complex simulation.
2. Redefinition of the ACTS display formats to utilize the capabilities of the MMDS.
3. Performance evaluation on the ACTS using synthetic and, if available, actual sea data.

Implementation of the above recommendations would provide the Center with a unique tool for evaluating computer-assisted classification and threat evaluation performance as well as determining the overall system feasibility of these concepts.

APPENDIX A

GENERATION OF SPLIT-BEAM DATA

The data generated for each Split-Beam Measurement Extractor display format simulates the returns from a single ping's transmission. Each format contains 250 range versus bearing samples, 250 range versus depression angle samples, and 250 range versus amplitude samples as background data. The bearing and depression angle samples for each of the 250 4-yard range resolution elements are generated from a uniform distribution in the interval [-2.5,+ 2.5] degrees. The amplitude samples are more difficult to generate and are selected from a Rayleigh distribution as follows:

1. Select 250 numbers (X_i) from a uniform distribution in the interval [0,1], i = 1,2,...,250.

2. For each X_i compute a value for sample amplitude (r_i) from

$$r_i = \sqrt{(-2)\ln X_i}$$

The simulated target return(s) can then be generated and are superimposed over the background data. Values for target depth, target range, and bottom depth are selected by the display operator. The values for target aspect angle, range extent, bearing extent, depression angle extent, target bearing, target depression angle, transmission depression angle, average S/N level ($\overline{S/N}$), and number of multipath returns are automatically selected from separate uniform distributions. The intervals for these distributions are fixed by system or physical constraints or are functions of the values selected by the operator.

From the selected average target S/N level, it is possible to associate a separate S/N ratio for each sample within the target echo and its multipath echoes. This is done in the following manner:

1. Select a sample (U_i) from a uniform distribution in the interval [0,1].

2. Compute a value for R_i from a Rayleigh distribution

$$R_i = \frac{4}{5}\ (\overline{S/N})\ \sqrt{(-2)\ln U_i}$$

3. Evaluate A_i where

$$A_i = (.22)R_{i-1} + (.78)A_{i-1}$$

$$A_o = 0$$

4. Repeat steps 1-3, about 100 times, until the running average of the computed A_i values becomes steady.

5. Associate an S/N ratio with each of the k target samples by

$$S/N_k = 20\ \log_{10} \frac{A_i}{\sqrt{2}},\ i \geq 100$$

With an S/N_k computed for each target sample, the noiseless range versus bearing and range versus depression angle display coordinates computed for the target samples can be modified by the addition of positional Gaussian noise. This positional noise is added to each sample in terms of fractions of degrees of bearing or depression angle. The amount of positional noise is determined by sampling a Gaussian distribution whose standard deviation is a function of the S/N_k ratio computed for the target samples. A table has been computed which relates standard deviation of the Gaussian positional noise distribution with the sample S/N ratio.[7]

Finally, the amplitude values for each target sample are computed from a Rice distribution as follows:

1. Select samples (V_i, W_i) from separate uniform distributions in the interval [0,1].

2. Compute the amplitude (r_i) for each target sample from

$$r_i = \sqrt{(-2)\ln V_i + 2A_i\sqrt{(-2)\ln V_i}\cos 2\pi W_i + A_i^2}$$

using the previously computed value for A_i.

APPENDIX B

GENERATION OF PREFORMED BEAM DATA

The simulated preformed beam data consists of 250 thresholded amplitude samples in the target doppler channel of the target preformed beam. A Rayleigh distribution is first used to generate 250 background amplitude samples. The procedure is the following:

1. Select 250 numbers (X_i) from a uniform distribution in the interval [0,1], i = 1,2,...,250.

2. If $U_i \geq 0.05$ (5 percent of the interval), set the sample amplitude (r_i) equal zero. Otherwise, compute a value for sample amplitude from

$$r_i = \sqrt{(-2)\ln X_i}$$

This technique simulates the application of a 5 percent amplitude threshold on the incoming data by permitting only about 5 percent of the amplitude samples to be non-zero.

The target return(s) are then generated and superimposed on the background data. The target is specified in terms of range within the range gate, range extent, number of multipath returns and average target S/N ratio ($\overline{S/N}$). The amplitudes for the target samples are computed in the following manner:

1. Select a sample (U_i) from a uniform distribution in the interval [0,1].

2. Compute a value for R_i from a Rayleigh distribution.

$$R_i = \frac{4}{5} \; (\overline{S/N}) \sqrt{(-2)\ln U_i}$$

3. Evaluate A_i

where
$$A_i = (.22)R_{i-1} + (.78)A_{i-1}$$
$$A_o = 0$$

4. Repeat steps 1-3, about 100 times, until the running average of the comuted A_i values becomes steady.

5. Select samples (V_i,W_i) from separate uniform distributions in the interval [0,1].

6. **Using a Rice distribution, compute the amplitude (r_i) for each target sample from**

$$r_i = \sqrt{(-2)\ln V_i + 2A_i\sqrt{(-2)\ln V_i'}\cos 2\pi W_i + A_i^2}$$

APPENDIX C

EVALUATION OF PREFORMED BEAM MEASUREMENT EXTRACTOR

A series of graphs was prepared as the result of a preliminary evaluation of the performance of the Preformed Beam Measurement Extractor routines using an artificial data base. The variables used in this evaluation were: target S/N ratio (0 dB through +20 dB), echo length (16, 64, and 104 yards), multipath condition (initial echo only, initial echo and first multipath, and initial echo and both multipaths), echo separation distance (applicable only when one or both multipath returns were present) (20, 40, and 80 yards), and amplitude threshold setting (4, 6, 8, and 10 percent). The Preformed Beam Measurement Extractor routines were considered to have successfully isolated a target when the extracted measurements for target range within the range gate, target range extent, and separation distance between target multipath returns (when computable) were each in error by less than 10 yards.

Each graph produced showed the percentage of targets detected versus S/N ratio for each of four amplitude threshold settings with a combination of the other variables held constant. In all, 84 separate combinations of echo length, separation distance, multipath condition, and threshold setting were evaluated as a function of target S/N ratio. The percentage performance for each S/N ratio was based on the number of times correct sets of target measurements were extracted out of 100 attempts.

The performance of the extractor in terms of correct values for targets detected increased monotonically with target signal-to-noise ratio as expected. A 50 percent performance level was achieved with an S/N of approximately 3 dB, and a 100 percent performance level with an S/N in the neighborhood of +7 dB.

APPENDIX D

LOGIC EQUATIONS FOR TARGET CLASS CATEGORIES

The six Boolean logic equations which define the target class categories (TC[i]) are presented below, with the definitions for the target parameter abbreviations used being given first. In these equations the + sign means the Boolean "OR" operation, and * is the "AND" operation.

DAEQ = Quantized depression angle extent
IFF = Identification Friend or Foe
ITSDO =
TBEQ = Quantized target bearing extent
TDI = Target depth indicator
TDQ = Quantized target depth
TINCQ = Quantized target inclination
TLQ = Quantized target length
TSQ = Quantized target speed

TC[1] (Submarine) = (IFF = 1) + {(TSQ[1]+...+TSQ[10]*(TLQ[2]+...+TLQ[14])*
(TDQ[1]+...+TDQ[22])*(TINCQ[3]+...+TINCQ[12])}
+ {(TSQ[1]+...+TSQ[10]*(TLQ[2]+...+TLQ[14])*
· (TINCQ[3]+...=TINCQ[12])*(TDI=1)*(ITSDO=1)}

TC[2] (Surface) = (IFF = 2) + {TSQ[1]+...+TSQ[10])*(TDQ[1]+TDQ[2]*
(TINCQ[3]+...+TINCQ[9])}+{(TSQ[1]+...
+TSQ[10])*(TINCQ[3]+...+TINCQ[9])*(TDI=0)*(ITSDO=1)}

TC[3] (Torpedo) = (IFF = 3) + (TSQ[5]+...+TSQ[11])*(TLQ[1]+TLQ[2])
*(TINCQ[3]+...+TINCQ[12])

TC[4] (Missile) = (IFF = 4) + (TSQ[9]+...+TSQ[11])*(TLQ[1]+...+TLQ[4])*
(TDQ[1]+...+TDQ[20])*(TINCQ[1]+...+TINCQ[3])

TC[5] (Counter Measure) = (IFF = 5) +[(TSQ[1]+...+TSQ[10])*(TLQ[1]+...+TLQ[15])
$\overline{\text{(TDQ[23])}}$(TINCQ[3]+...+TINCQ[12])*(TDI=1)]
*[(TBEQ[1]) + (DAEQ[1])]

TC[6] (Other) = (IFF = 6) + $\overline{\text{(TC[1] + TC[2] + TC[3] + TC[4] + TC[5])}}$

APPENDIX E

LOGIC EQUATIONS FOR SINGLE-PING TARGET TACTICS CATEGORIES

The following are the 21 Boolean logic equations which define the single-ping target tactics categories (TT[i]) (The definitions for the abbreviations of the target parameters used are presented first.) In these equations, the + sign means the Boolean "OR" operation and * is the "AND" operation.

HTRQ = Quantized horizontal target range

TAAQ = Quantized target aspect angle

TDQ = Quantized target depth

TSQ = Quantized target speed

$$\mathrm{TT}[1] = (\mathrm{HTRQ}[1] + \mathrm{HTRQ}[2])*(\mathrm{TAAQ}[1] +\ldots+\mathrm{TAAQ}[7] + \mathrm{TAAQ}[30]+\ldots+\mathrm{TAAQ}[36])*(\mathrm{TDQ}[1]+\ldots+\mathrm{TDQ}[10])*(\mathrm{TSQ}[4]+\ldots+\mathrm{TSQ}[11])$$

$$\mathrm{TT}[2] = (\mathrm{HTRQ}[1] + \mathrm{HTRQ}[2])*(\mathrm{TAAQ}[1]+\ldots+\mathrm{TAAQ}[7]+\mathrm{TAAQ}[30]+\ldots+\mathrm{TAAQ}[36])*(\mathrm{TDQ}[1]+\ldots+\mathrm{TDQ}[10])*(\mathrm{TSQ}[1]+\ldots+\mathrm{TSQ}[3])$$

$$\mathrm{TT}[3] = (\mathrm{HTRQ}[1] + \mathrm{HTRQ}[2])*(\mathrm{TAAQ}[1]+\ldots+\mathrm{TAAQ}[7]+\mathrm{TAAQ}[30]+\ldots+\mathrm{TAAQ}[36])*(\mathrm{TDQ}[11]+\ldots+\mathrm{TDQ}[23])*(\mathrm{TSQ}[4]+\ldots+\mathrm{TSQ}[11])$$

$$\mathrm{TT}[4] = (\mathrm{HTRQ}[1] + \mathrm{HTRQ}[2])*(\mathrm{TAAQ}[1]+\ldots+\mathrm{TAAQ}[7]+\mathrm{TAAQ}[30]+\ldots+\mathrm{TAAQ}[36])*(\mathrm{TDQ}[11]+\ldots+\mathrm{TDQ}[23])*(\mathrm{TSQ}[1]+\ldots+\mathrm{TSQ}[3])$$

$$\mathrm{TT}[5] = (\mathrm{HTRQ}[1] + \mathrm{HTRQ}[2])*(\mathrm{TAAQ}[8]+\ldots+\mathrm{TAAQ}[11]+\mathrm{TAAQ}[26]+\ldots+\mathrm{TAAQ}[29])*(\mathrm{TDQ}[1]+\ldots+\mathrm{TDQ}[10])*(\mathrm{TSQ}[4]+\ldots+\mathrm{TSQ}[11])$$

$$\mathrm{TT}[6] = (\mathrm{HTRQ}[1] + \mathrm{HTRQ}[2])*(\mathrm{TAAQ}[8]+\ldots+\mathrm{TAAQ}[11]+\mathrm{TAAQ}[26]+\ldots+\mathrm{TAAQ}[29])*(\mathrm{TDQ}[1]+\ldots+\mathrm{TDQ}[10])*(\mathrm{TSQ}[1]+\ldots+\mathrm{TSQ}[3])$$

```
TT[7] = (HTRQ[1]+HTRQ[2])*(TAAQ[8]+...+TAAQ[11]+TAAQ[26]+...+
        TAAQ[29])*(TDQ[11]+...+TDQ[23])*(TSQ[4]+...+TSQ[11])

TT[8] = (HTRQ[1]+HTRQ[2])*(TAAQ[8]+...+TAAQ[11]+TAAQ[26]+...+
        TAAQ[29])*(TDQ[11]+...+TDQ[23])*(TSQ[1]+...+TSQ[3])

TT[9] = (HTRQ[1]+HTRQ[2])*(TAAQ[12]+...+TAAQ[25])*(TSQ[4]+...+
        TSQ[11])

TT[10] = (HTRQ[1]+HTRQ[2])*(TAAQ[12]+...+TAAQ[25])*(TSQ[1]+...+
         TSQ[3])

TT[11] = (HTRQ[3]+...+HTRQ[12])*(TAAQ[1]+...+TAAQ[7]+TAAQ[30]+...+
         TAAQ[36])*(TDQ[1]+...+TDQ[10])*(TSQ[4]+...+TSQ[11])

TT[12] = (HTRQ[3]+...+HTRQ[12])*(TAAQ[1]+...+TAAQ[7]+TAAQ[30]+...+
         TAAQ[36])*(TDQ[1]+...+TDQ[10])*(TSQ[1]+...+TSQ[3])

TT[13] = (HTRQ[3]+...+HTRQ[12])*(TAAQ[1]+...+TAAQ[7]+TAAQ[30]+...+
         TAAQ[36])*(TDQ[11]+...+TDQ[23])*(TSQ[4]+...+TSQ[11])

TT[14] = (HTRQ[3]+...+HTRQ[12])*(TAAQ[1]+...+TAAQ[7]+TAAQ[30]+...+
         TAAQ[36])*(TDQ[11]+...+TDQ[23])*(TSQ[1]+...+TSQ[3])
```

TT[15] = (HTRQ[3]+...+HTRQ[12])*(TAAQ[8]+...+TAAQ[11]+TAAQ[26]+...+
TAAQ[29])*(TDQ[1]+...+TDQ[10])*(TSQ[4]+...+TSQ[11])

TT[16] = (HTRQ[3]+...+HTRQ[12])*(TAAQ[8]+...+TAAQ[11]+TAAQ[26]+...+
TAAQ[29])*(TDQ[1]+...+TDQ[10])*(TSQ[1]+...+TSQ[3])

TT[17] = (HTRQ[3]+...+HTRQ[12])*(TAAQ[8]+...+TAAQ[11]+TAAQ[26]+...+
TAAQ[29])*(TDQ[11]+...+TDQ[23])*(TSQ[4]+...+TSQ[11])

TT[18] = (HTRQ[3]+...+HTRQ[12])*(TAAQ[8]+...+TAAQ[11]+TAAQ[26]+...+
TAAQ[29])*(TDQ[11]+...+TDQ[23])*(TSQ[1]+...+TSQ[3])

TT[19] = (HTRQ[3]+...+HTRQ[12])*(TAAQ[12]+...+TAAQ[25]*(TSQ[4]+...+
TSQ[11])

TT[20] = (HTRQ[3]+...+HTRQ[12])*(TAAQ[12]+...+TAAQ[25])*(TSQ[1]+...+
TSQ[3])

TT[21] = HTRQ[13]

APPENDIX F

Logic Equations for Target Threat Level Categories

The following five Boolean logic equations define the target threat level categories (TTL[i]). In the equations the + sign means the Boolean "OR" operation and the * is the "AND" operation.

TTL[1] (High) = {[TC[1]*(TT[1]+...+TT[8]+(TT[27]=3)+...+(TT[34]=3))]
+[TC[2]*(TT[1]+TT[2]+TT[5]+TT[6]+TT[9]+TT[10]
+(TT[27]=3)+...+(TT[31]=3)+(TT[34]=3))]
+[TC[3]*(TT[1]+...+TT[4]+TT[11]+...+TT[14]
+(TT[27]≥2)+(TT[29]≥2)+...+(TT[34]≥2))]
+[TC[4]]} *(IFF=0)

TTL[2] (Intermediate) = {[TC[1]*(TT[9]+...+TT[20]+(TT[26]≥2)+(TT[27]=2)+...+
(TT[34]=2))]
+[TC[2]*(TT[11]+TT[12]+TT[15]+TT[16]+TT[19]+TT[20]
+(TT[26]≥2)+(TT[27]=2)+...+(TT[31]=2)+(TT[34]=2))]
+[TC[3]*(TT[5]+...+TT[8]+TT[15]+...+TT[18]
+(TT[27]=1)+(TT[29]=1)+...+(TT[34]=1))]}*(IFF=0)

TTL[3] (low) = {[TC[1]*(TT[21]+(TT[27]=1)+...+(TT[34]=1))]
+[TC[2]*(TT[21]+(TT[27]=1)+...+(TT[31]=1)+(TT[34]=1)]
+[TC[3]*(TT[9]+TT[10]+TT[19]+TT[21]]+[TC[5]]}*(IFF=0)

TTL[4] (None) = 1 if $IFF \neq 0$

TTL[5] (Unknown) = $\overline{(TTL[1]+TTL[2]+TTL[3]+TTL[4])*(IFF=0)}$

APPENDIX G

SIMULATED 10-PING TARGET ENCOUNTER

This appendix illustrates the ping-by-ping development of a simulated 10-ping active target encounter as it appeared on each of the three ACTS classification and threat evaluation display formats. (Figs. G-1 through G-26). In a true operational situation, all of the formats shown here for each ping would probably not be required. For example, as the active track is initiated with the returns from the first few pings, the format of most interest would be the one showing the combined passive/active track history or, if a single-ping fire control solution is required, then the command and control/fire control format would be selected. As the returns from more active transmissions are added to the target's track history, the format showing only the active track history becomes the most useful. The command and control/fire control format can, of course, be selected at any time.

This simulated target encounter is between own-ship and a single target which is initially unalerted and motionless in the water (first three pings). The target is alerted by the active transmissions and reacts by beginning a series of defensive maneuvers. As the returns from each new ping are received and processed, the ACTS computes updated target class and threat level estimates and generates new display formats. On the tenth ping, it is determined from intelligence information that the target is a nonhostile submarine and the threat level is set to "NONE".

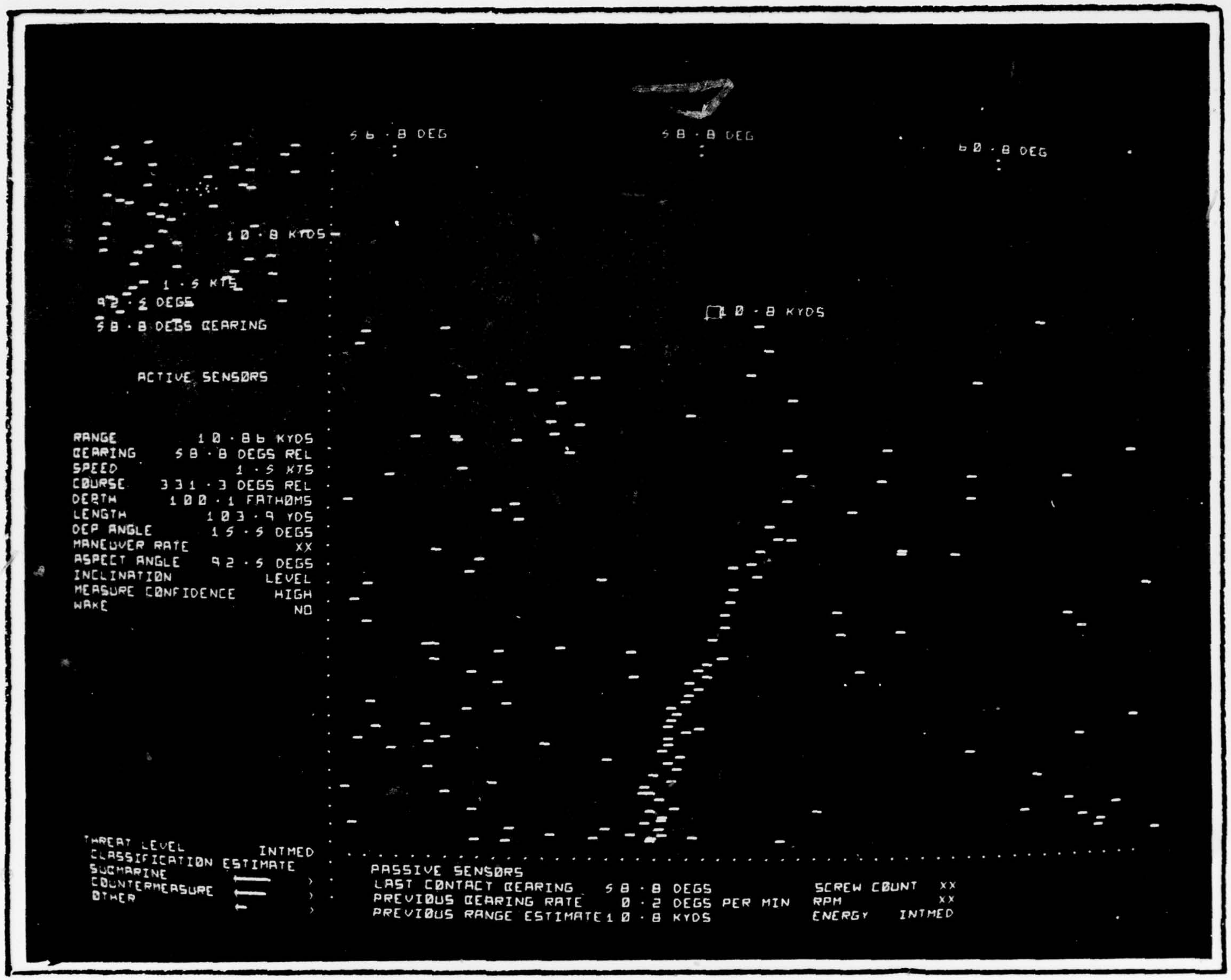


FIGURE G-1. Passive/Active Track History, First Ping.

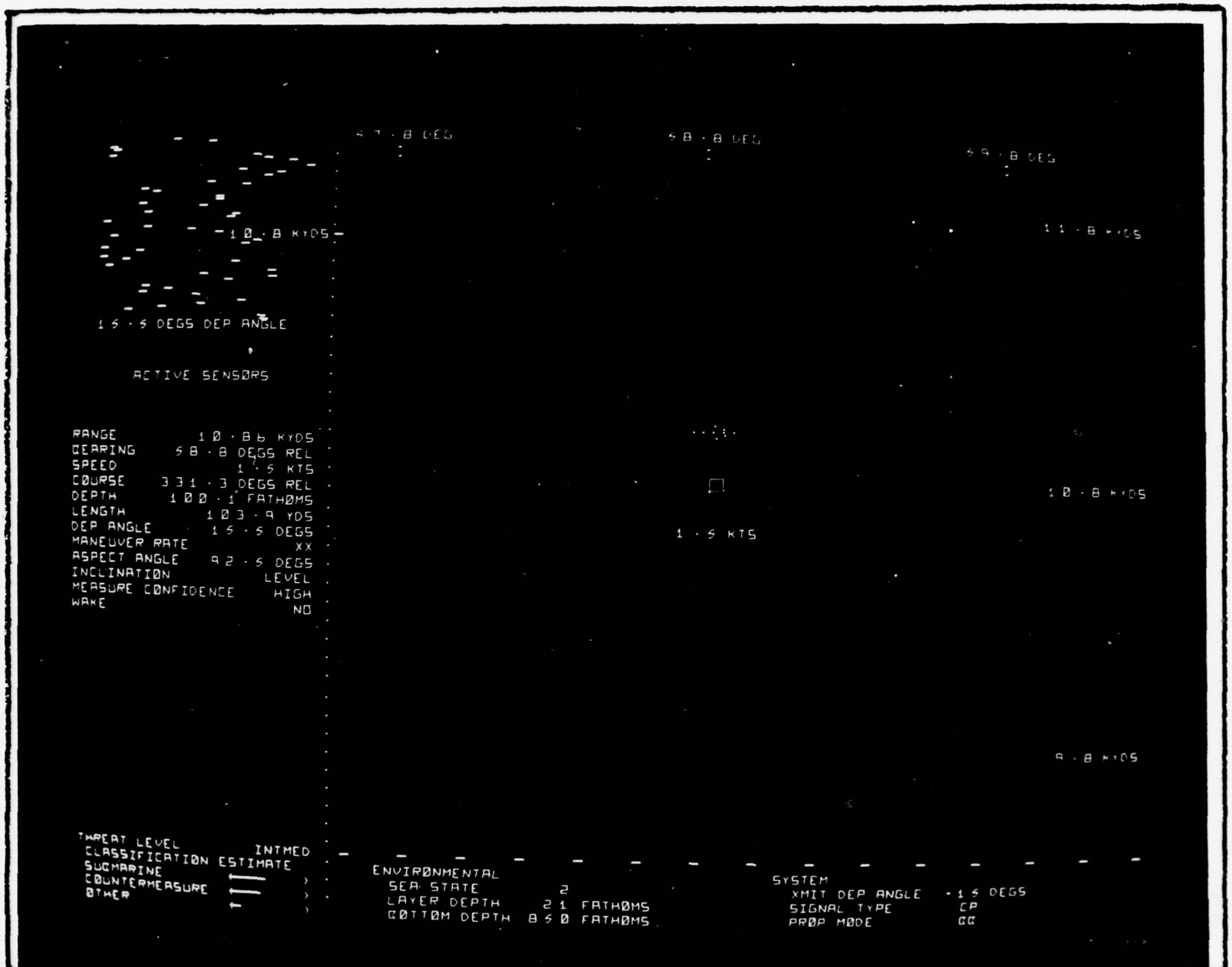


FIGURE G-2. Active Track History, First Ping.

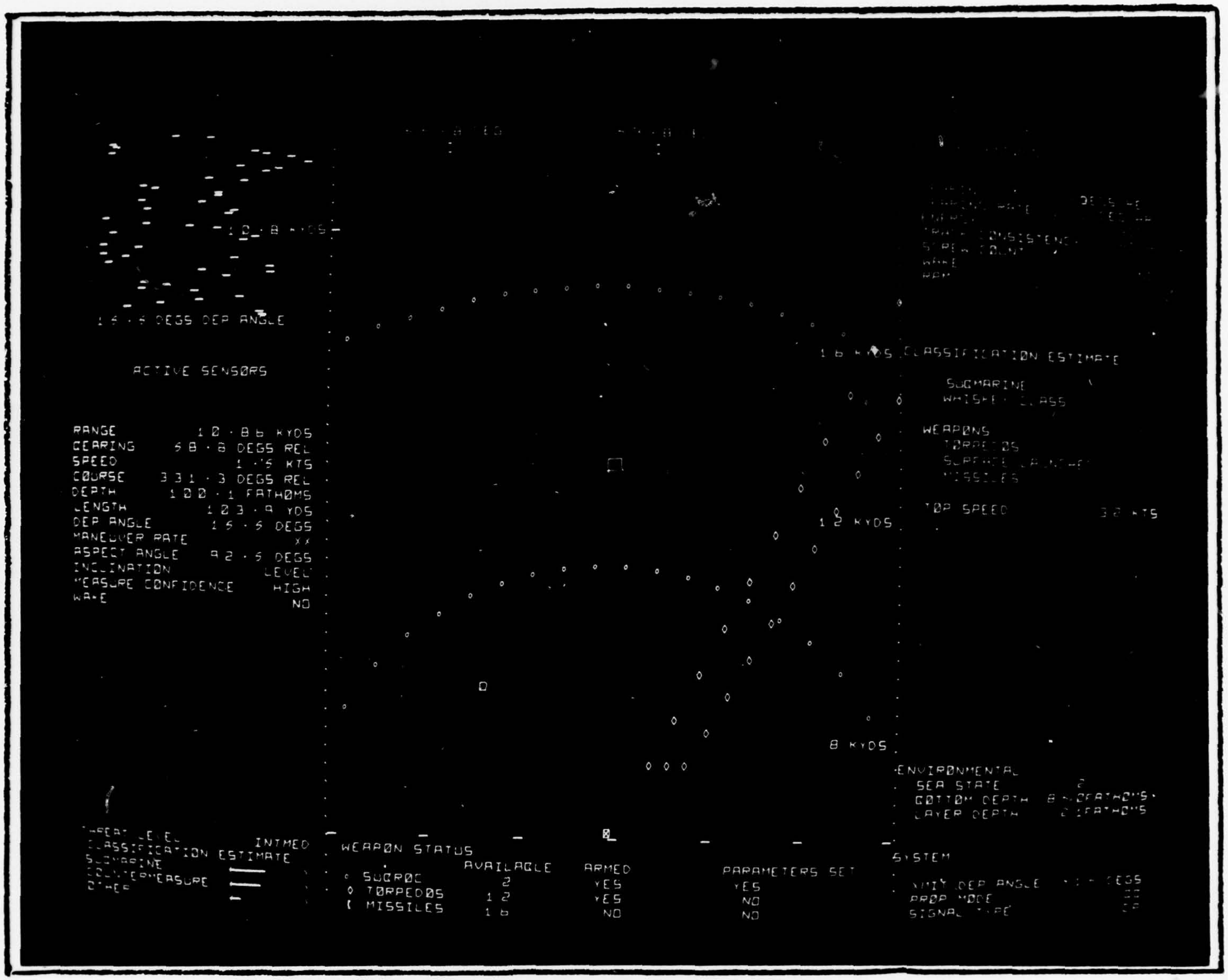


FIGURE G-3. Command and Control/Fire Control, First Ping.

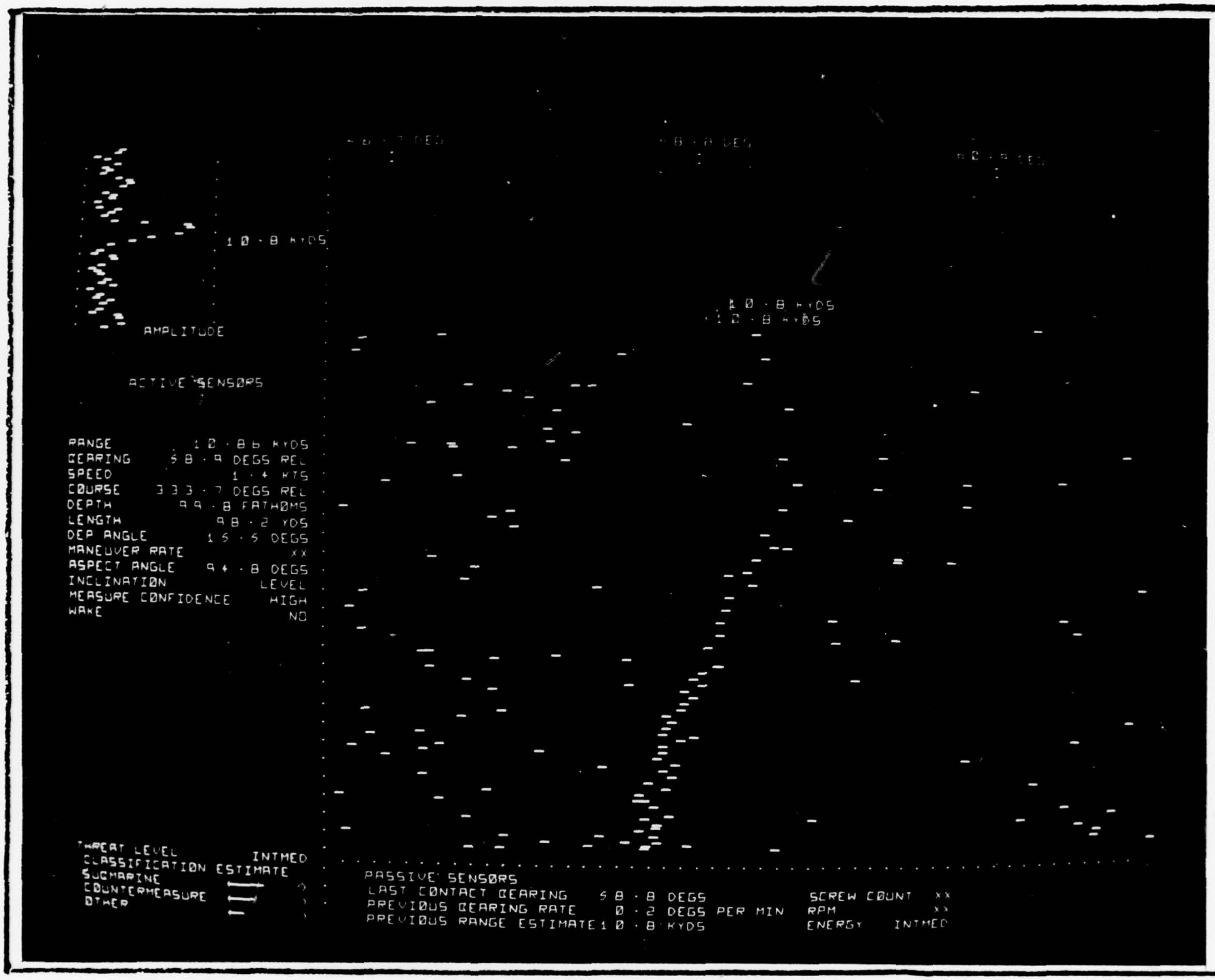


FIGURE G-4. Passive/Active Track History, Second Ping.

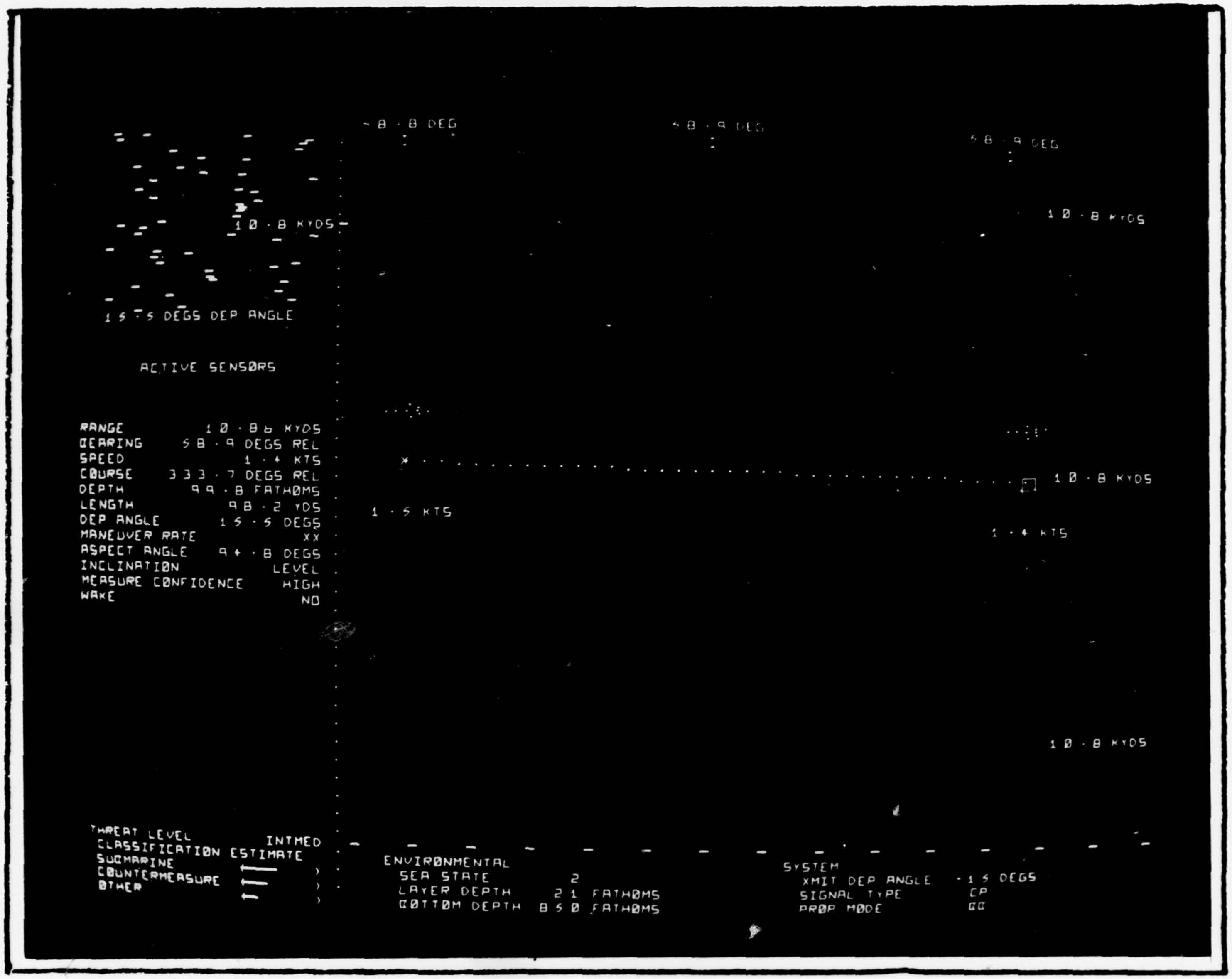


FIGURE G-5. Active Track History, Second Ping.

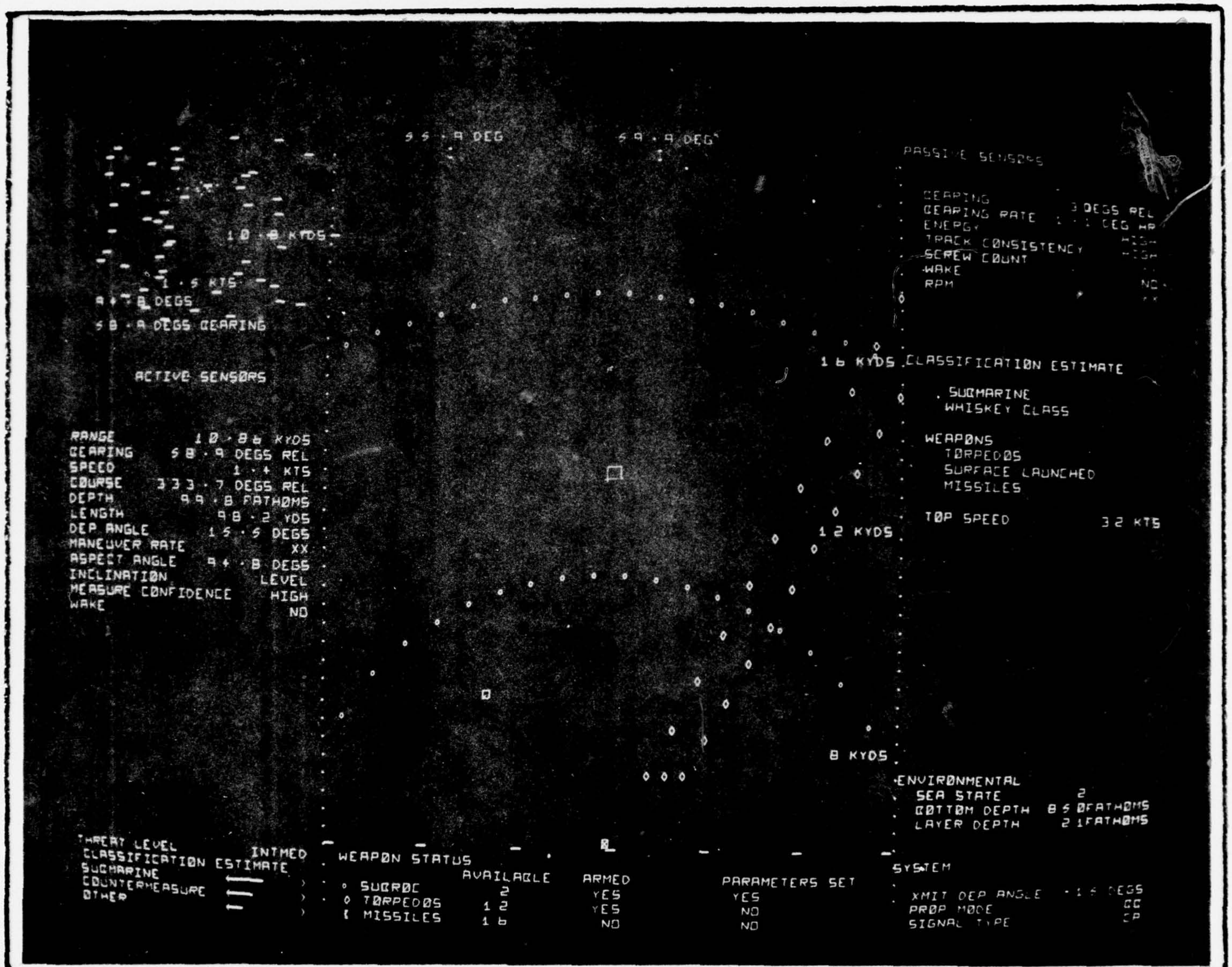


FIGURE G-6. Command and Control/Fire Control, Second Ping.

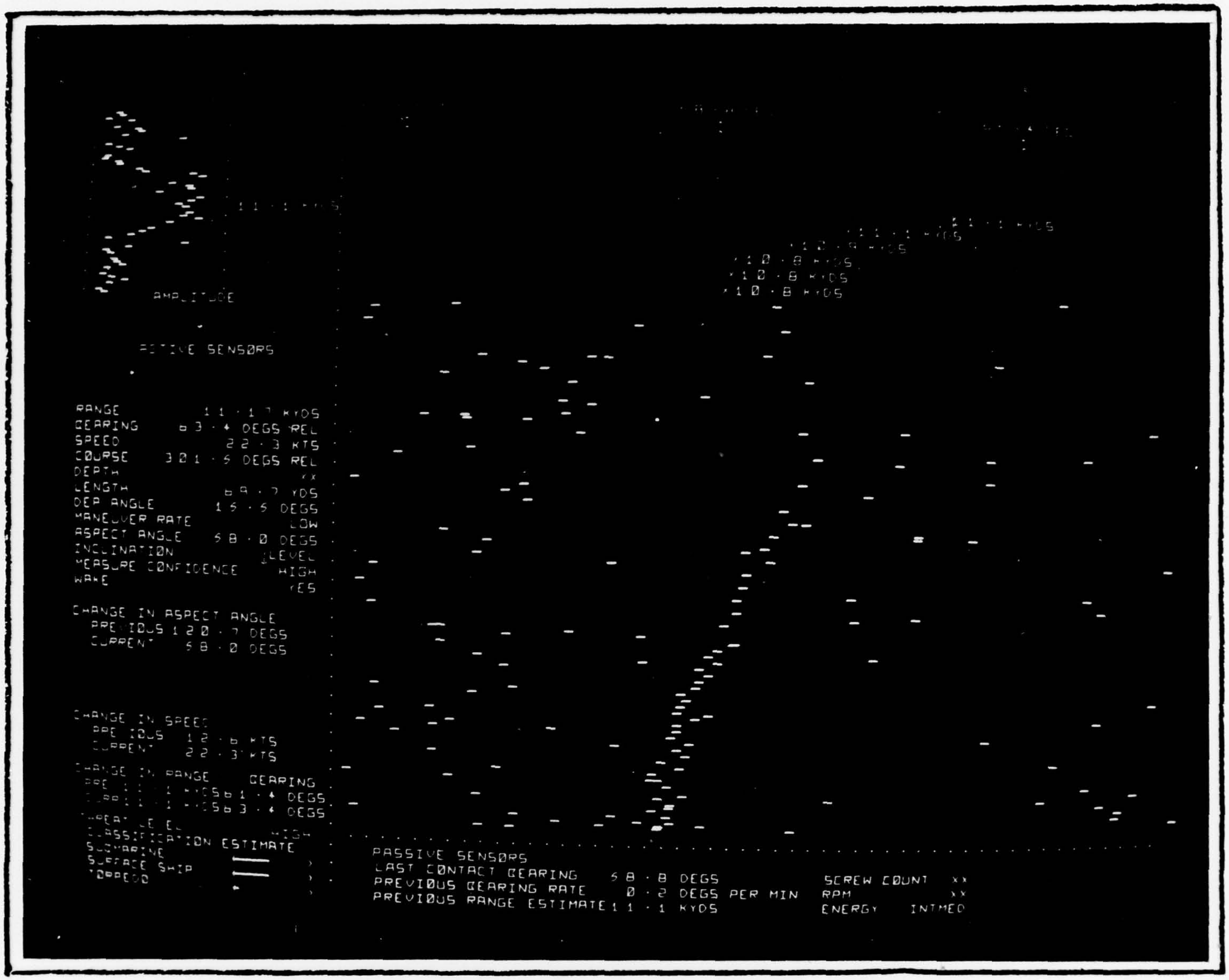


FIGURE G-7. Passive/Active Track History, Third Ping.

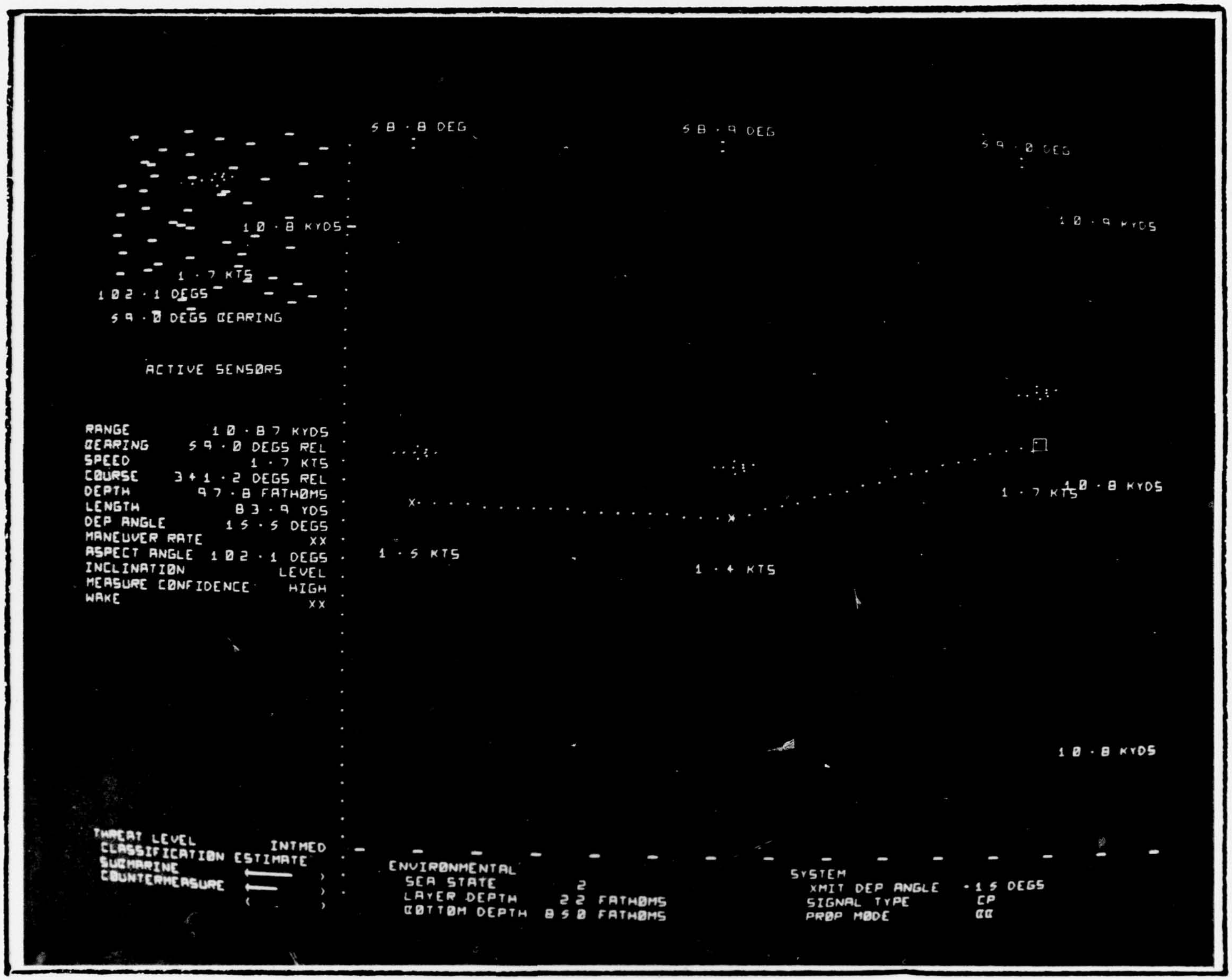


FIGURE G-8. Active Track History, Third Ping.

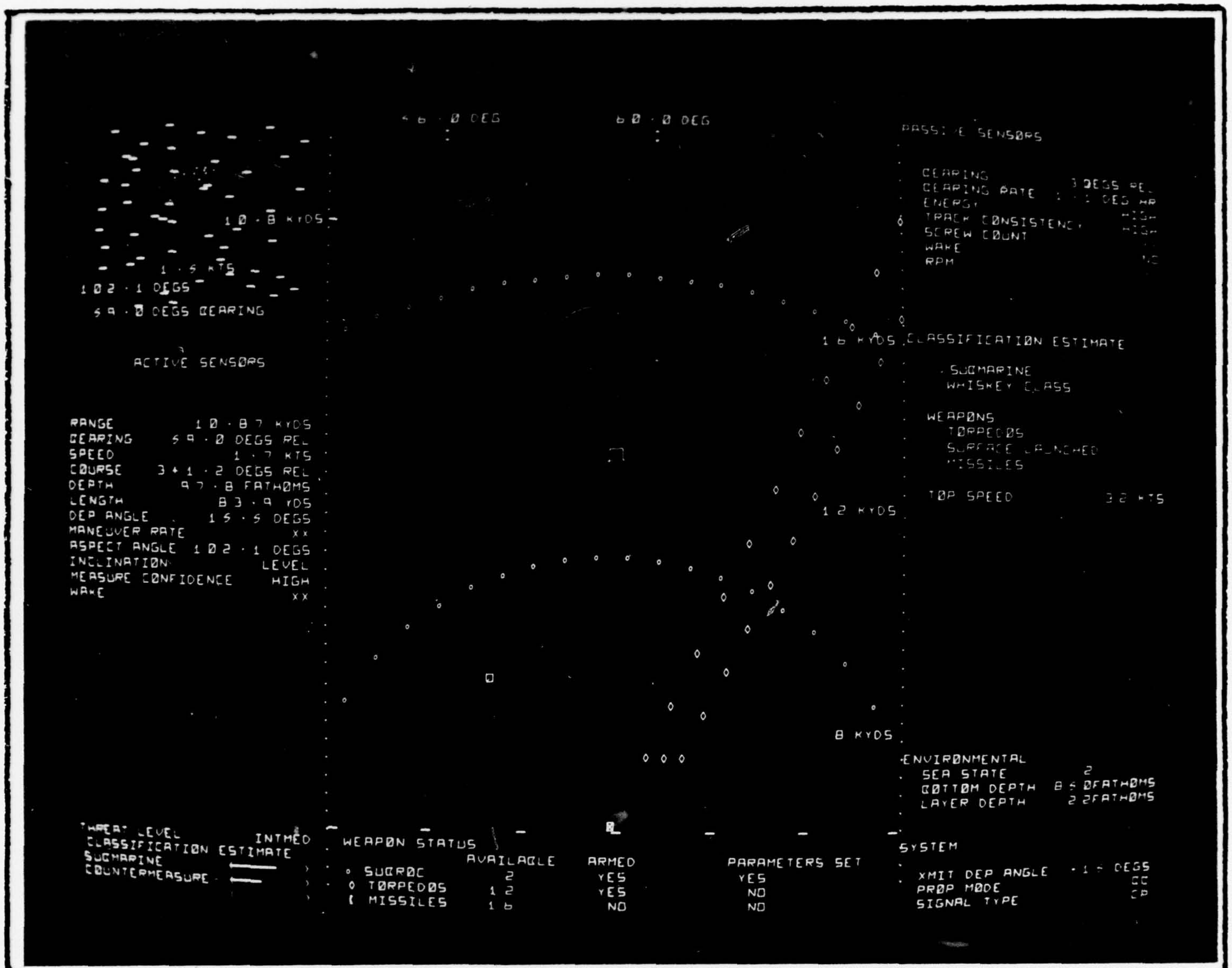


FIGURE G-9. Command and Control/Fire Control, Third Ping.

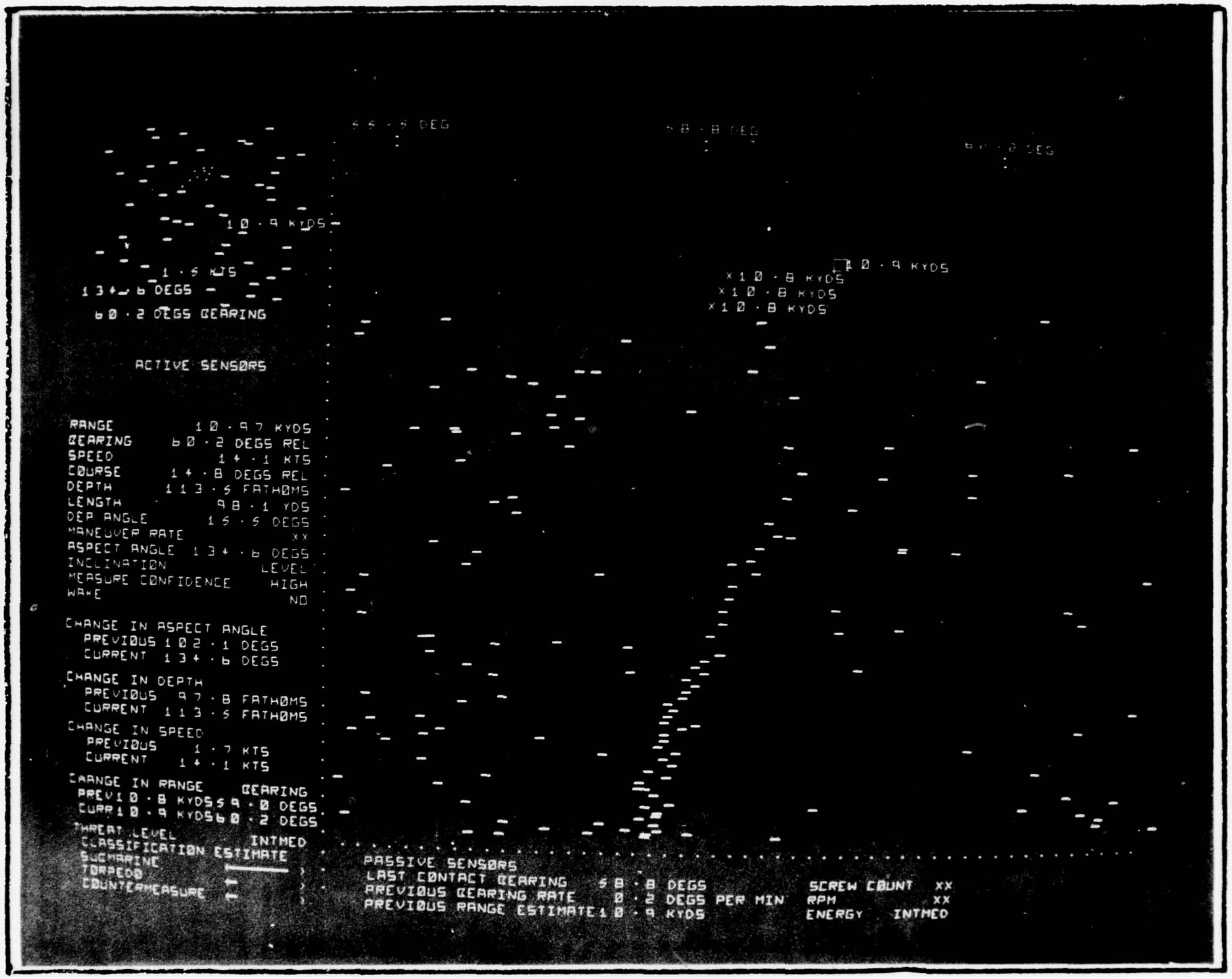


FIGURE G-10. Passive/Active Track History, Fourth Ping.

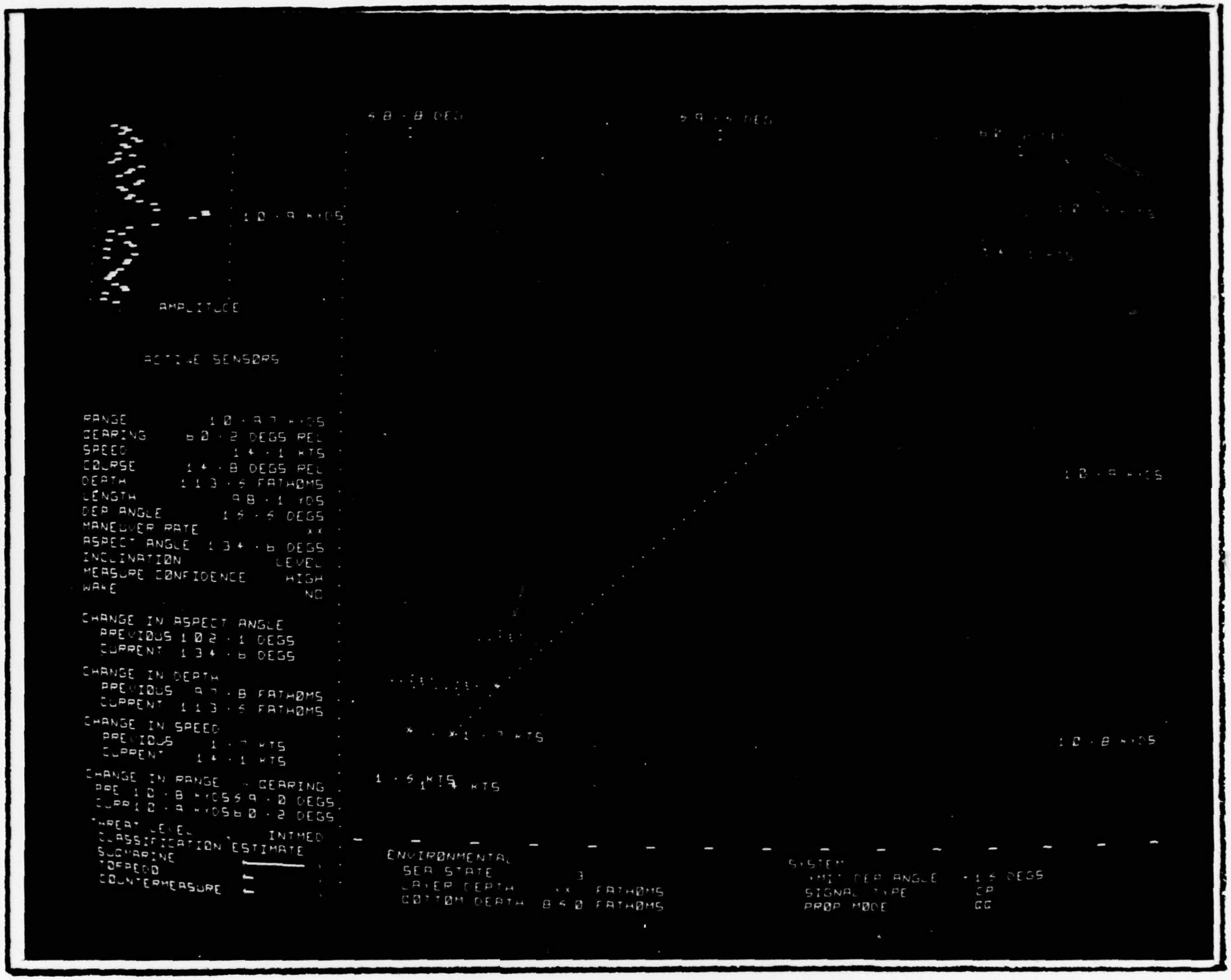


FIGURE G-11. Active Track History, Fourth Ping.

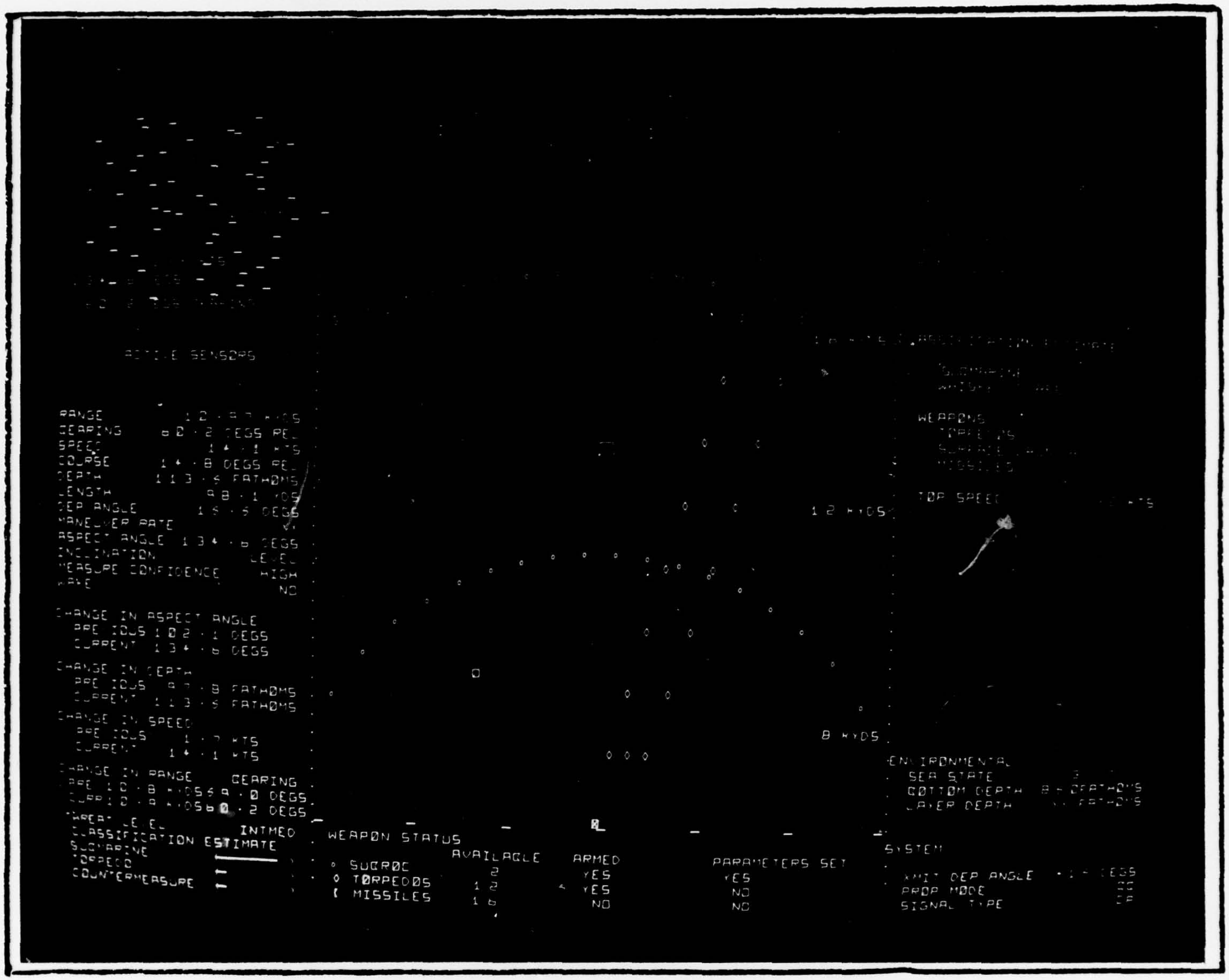


FIGURE G-12. Command and Control/Fire Control, Fourth Ping.

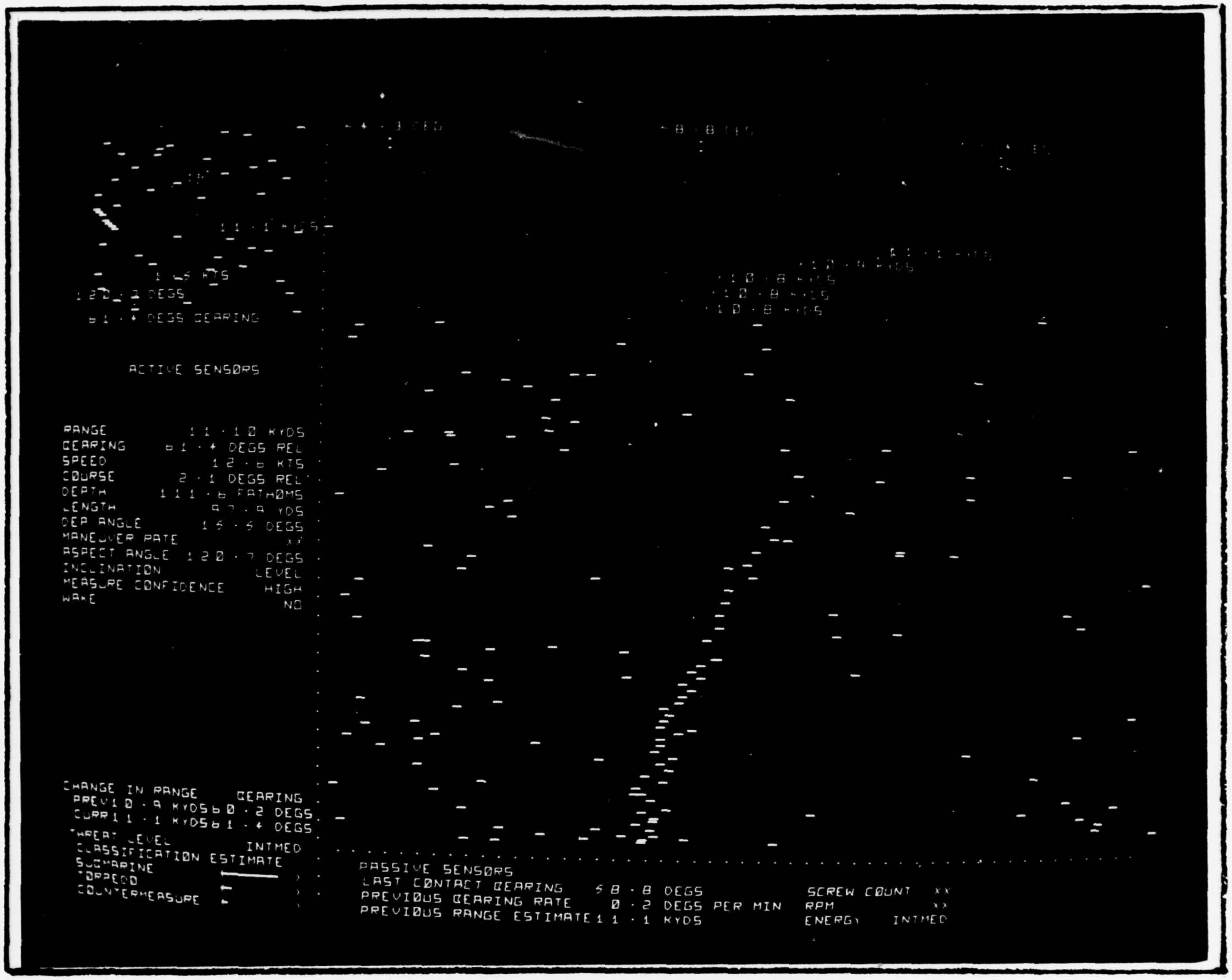
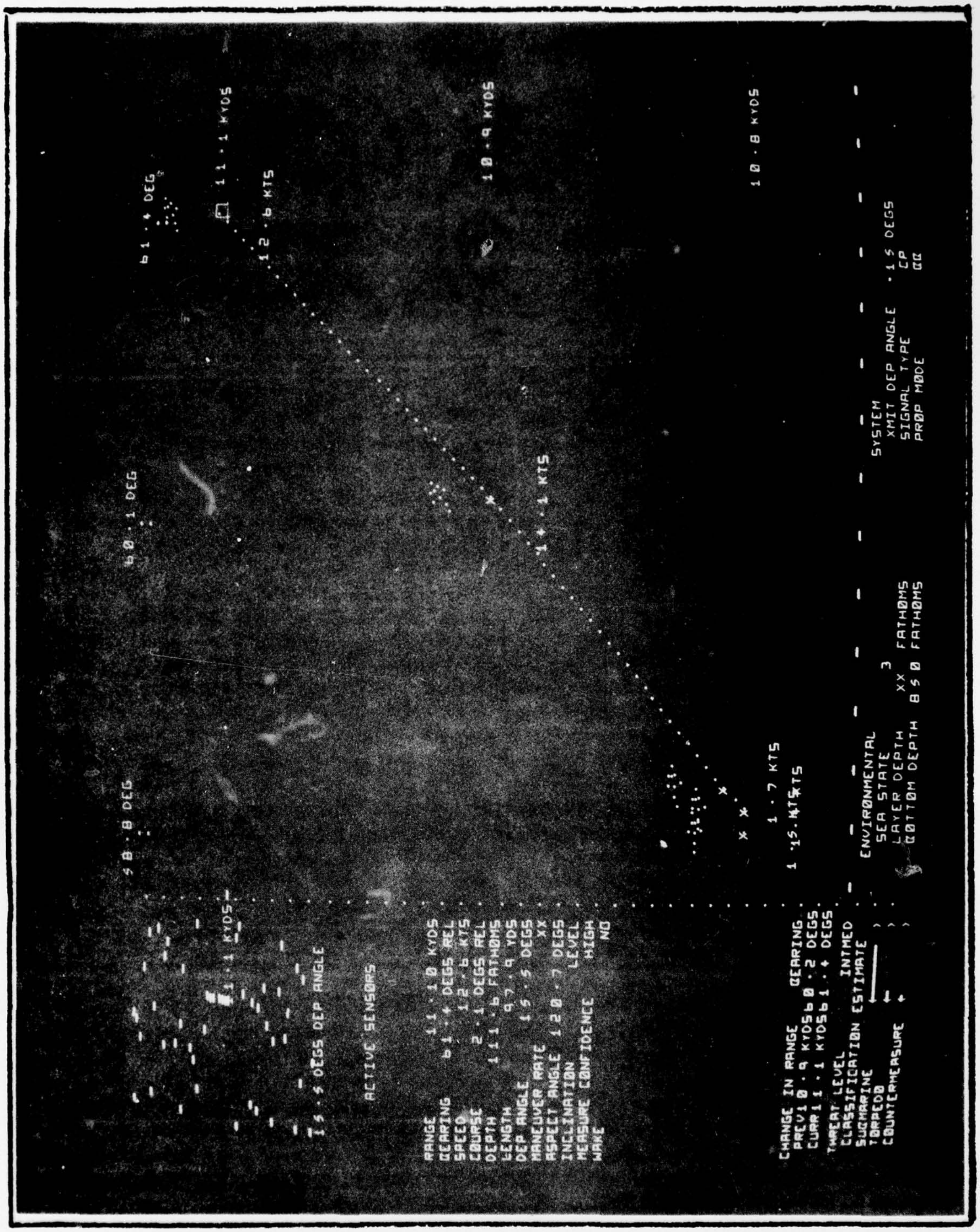


FIGURE G-13. Passive/Active Track History, Fifth Ping.



5 8 . 8 DEG
6 0 . 1 DEG
6 1 . 4 DEG
1 1 . 1 KYDS
1 1 . 1 KYDS
1 2 . 6 KTS
1 5 . 5 DEGS DEP ANGLE
ACTIVE SENSØRS
RANGE 1 1 . 1 0 KYDS
BEARING 6 1 . 4 DEGS REL
SPEED 1 2 . 6 KTS
COURSE 2 . 1 DEGS REL
DEPTH 1 1 1 . 6 FATHØMS
LENGTH 9 7 . 9 YDS
DEP ANGLE 1 5 . 5 DEGS
MANEUVER RATE XX
ASPECT ANGLE 1 2 0 . 7 DEGS
INCLINATIØN LEVEL
MEASURE CØNFIDENCE HIGH
WAKE NO
1 0 . 9 KYDS
1 4 . 1 KTS
1 0 . 8 KYDS
1 . 7 KTS
1 15. KTS KTS
CHANGE IN RANGE BEARING
PREV 1 0 . 9 KYDS 6 0 . 2 DEGS
CURR 1 1 . 1 KYDS 6 1 . 4 DEGS
THREAT LEVEL INTMED
CLASSIFICATIØN ESTIMATE
SUBMARINE
TØRPEDØ
CØUNTERMEASURE
ENVIRØNMENTAL
SEA STATE 3
LAYER DEPTH XX FATHØMS
BØTTØM DEPTH 8 5 0 FATHØMS
SYSTEM
XMIT DEP ANGLE . 1 5 DEGS
SIGNAL TYPE CP
PRØP MØDE BB

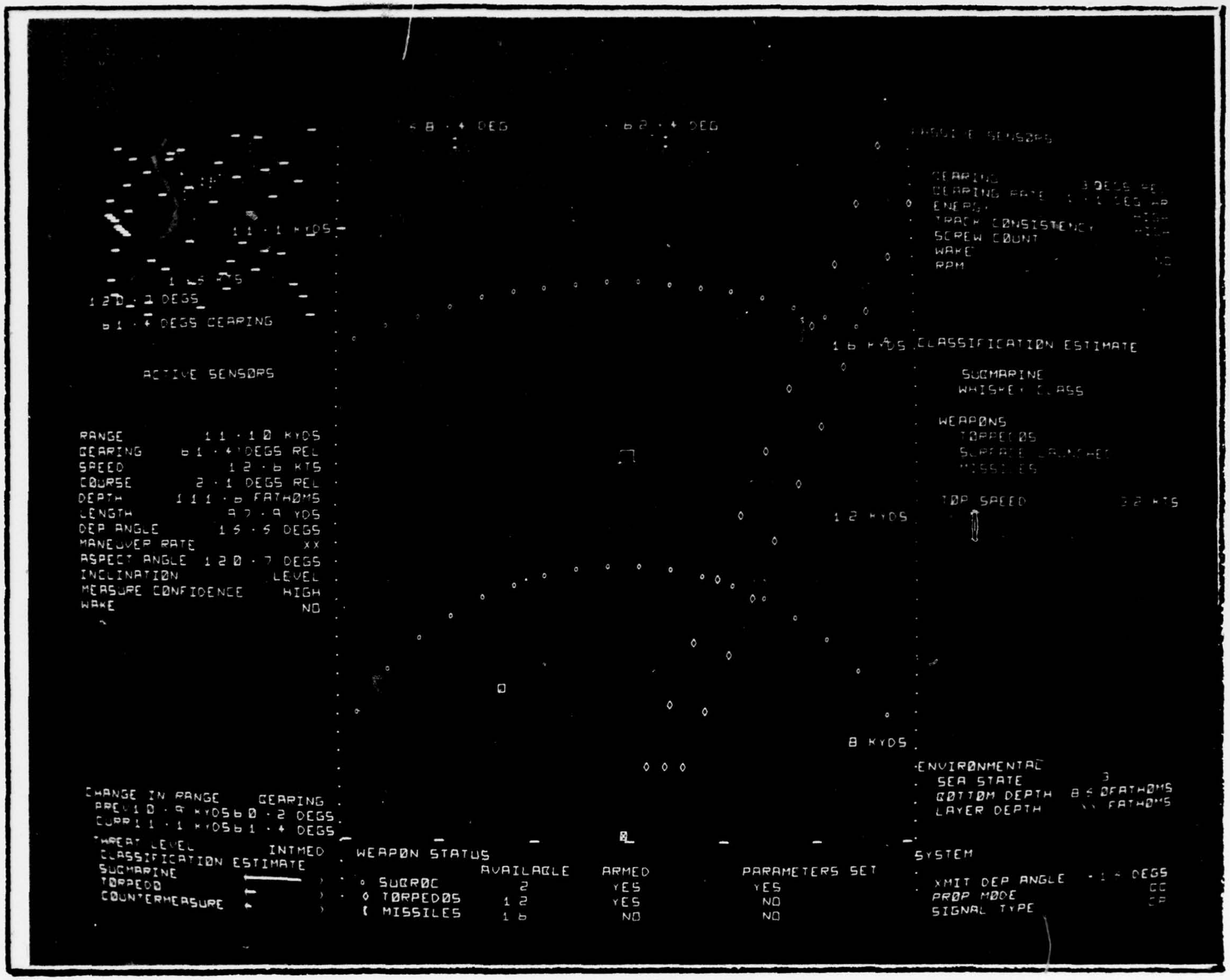


FIGURE G-15. Command and Contro/Fire Control, Fifth Ping.

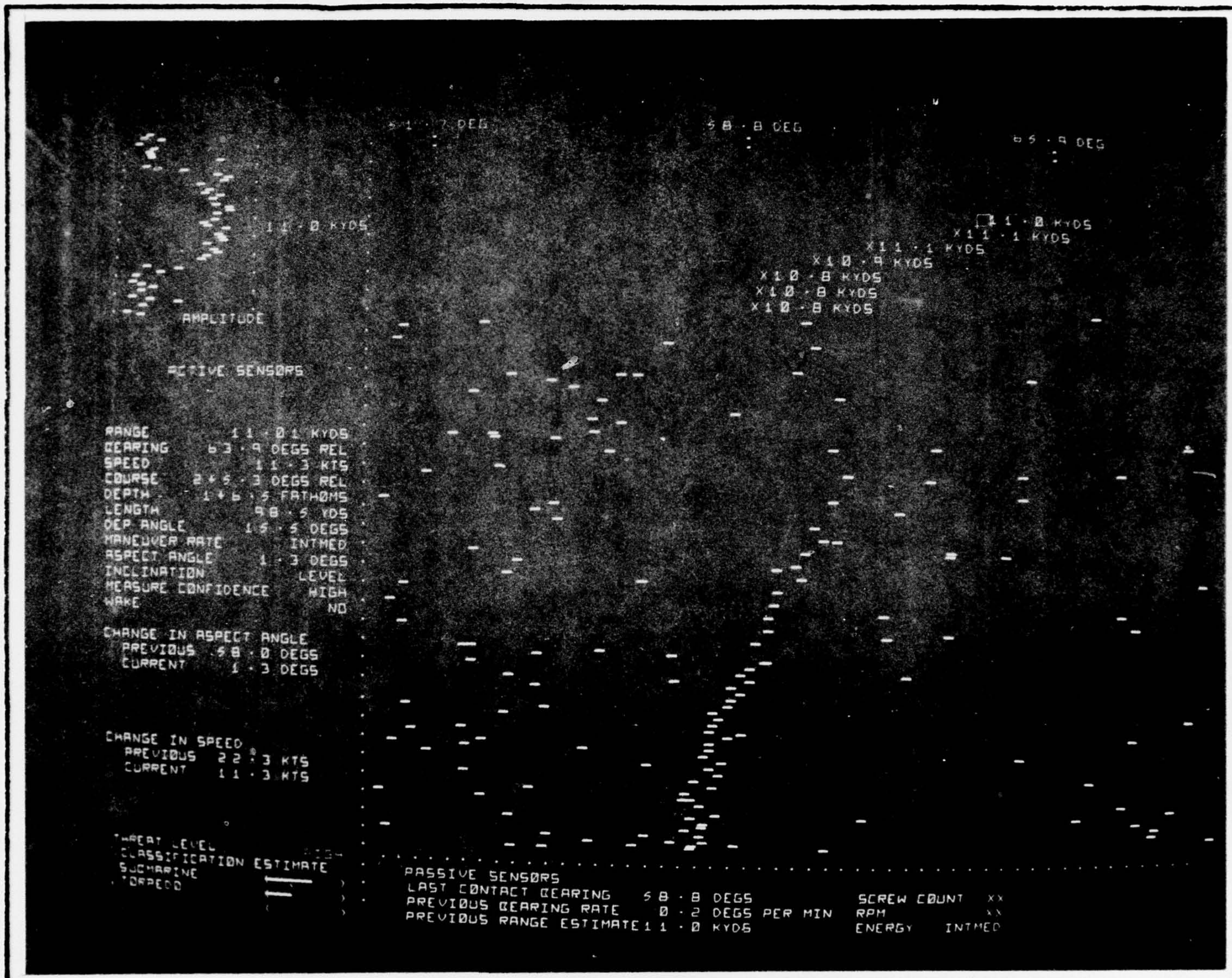


FIGURE G-16. Passive/Active Track History, Seventh Ping.

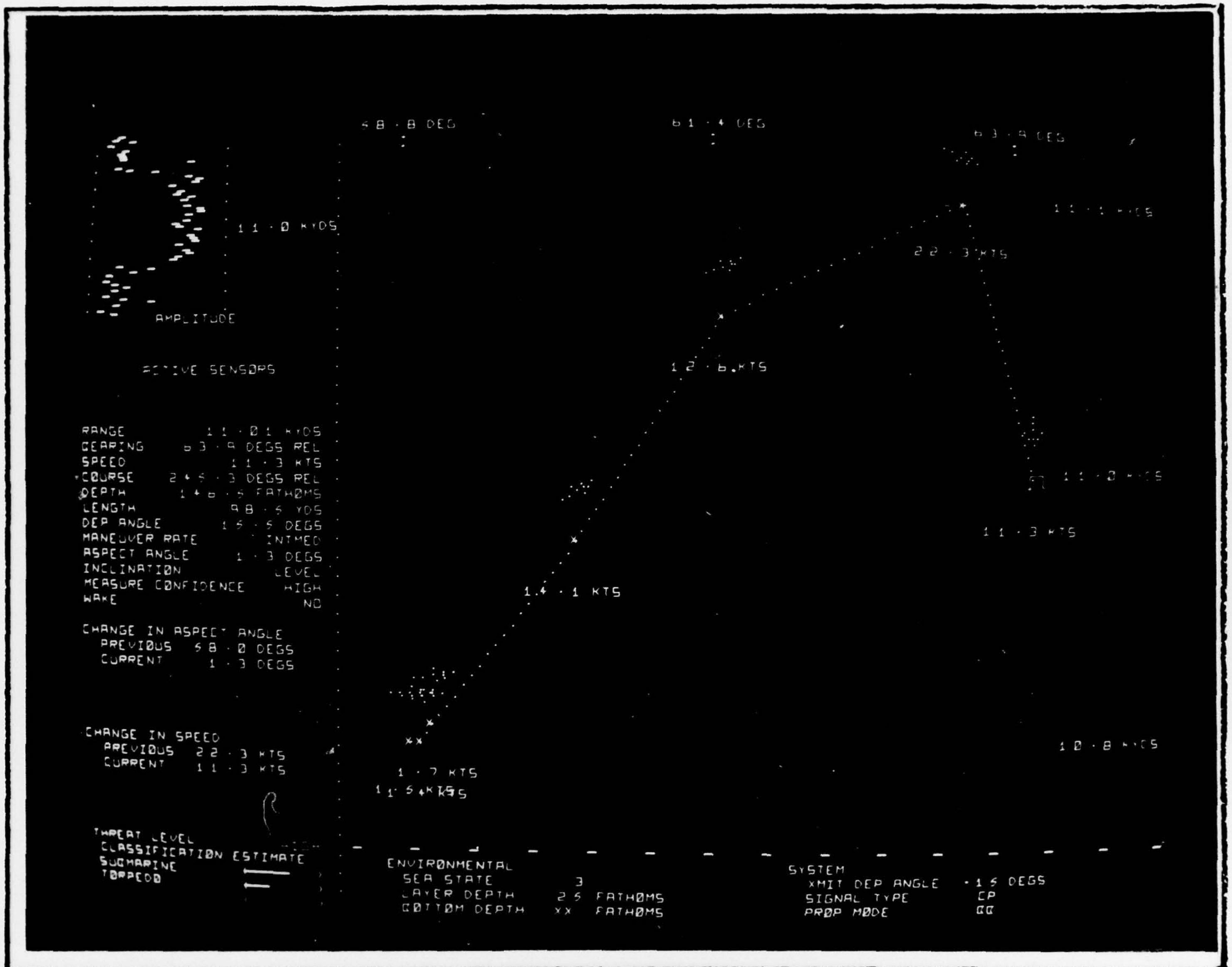


FIGURE G-17. Active Track History, Seventh Ping.

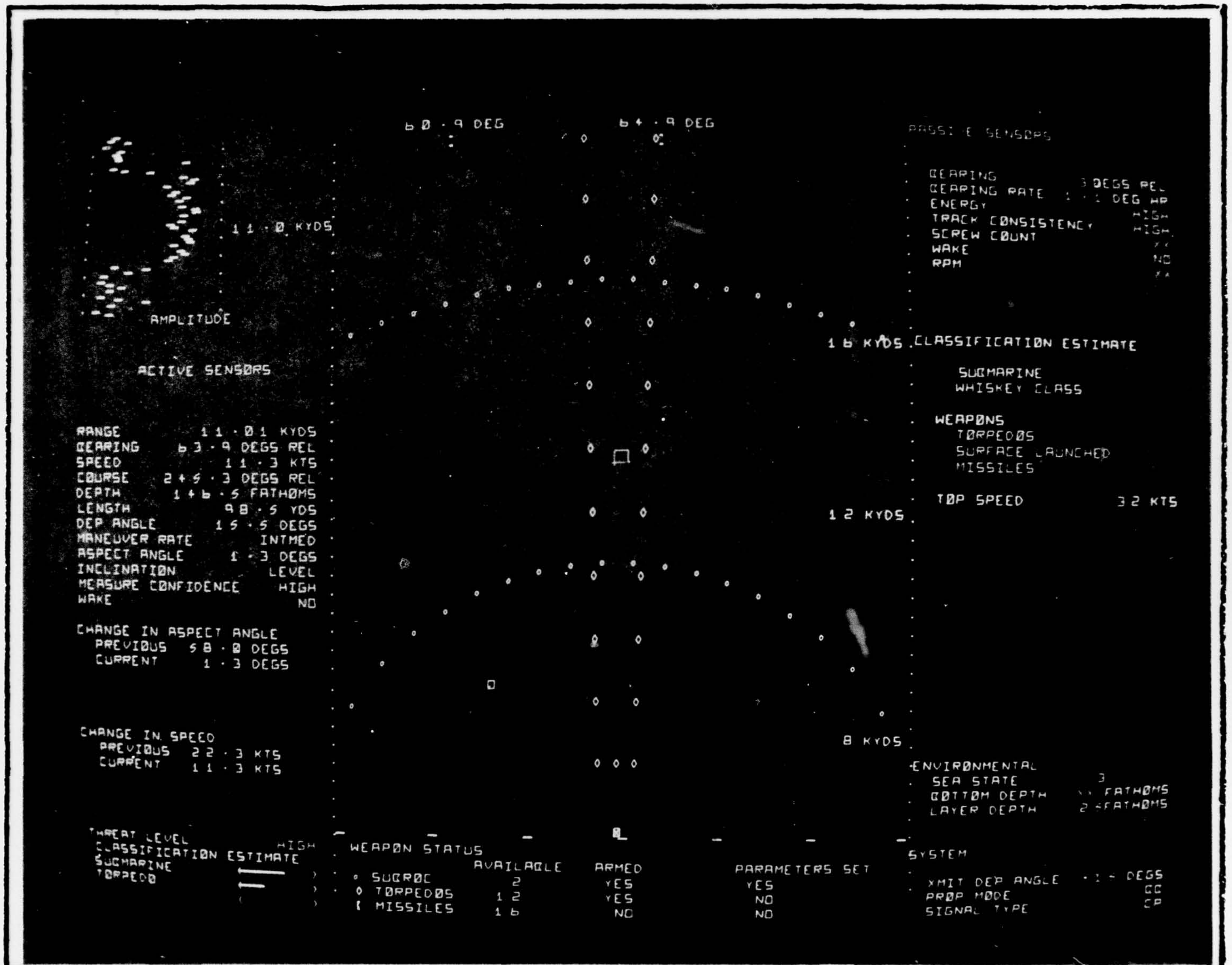


FIGURE G-18. Command and Control/Fire Control, Seventh Ping.

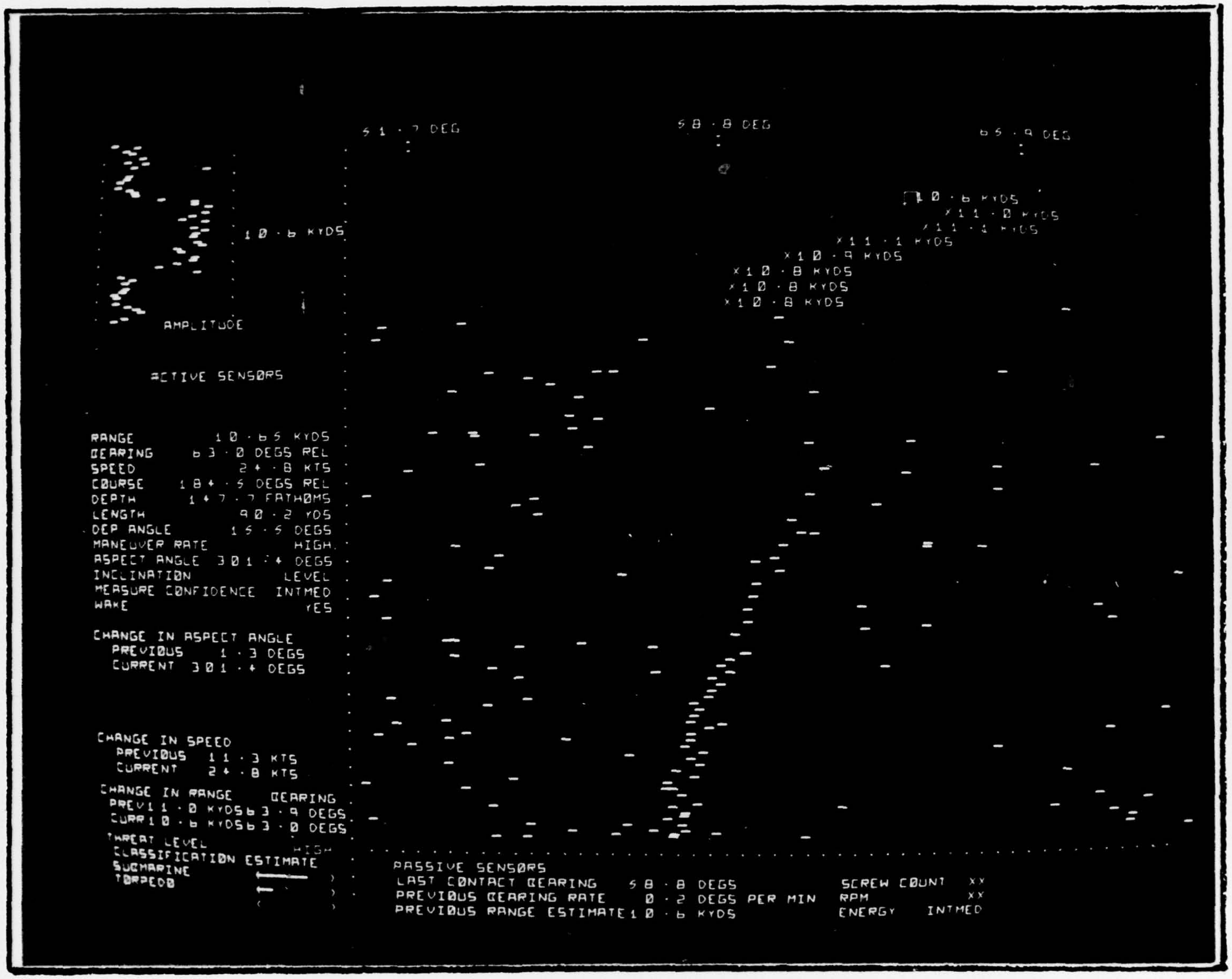


FIGURE G-19. Passive/Active Track History, Eighth Ping.

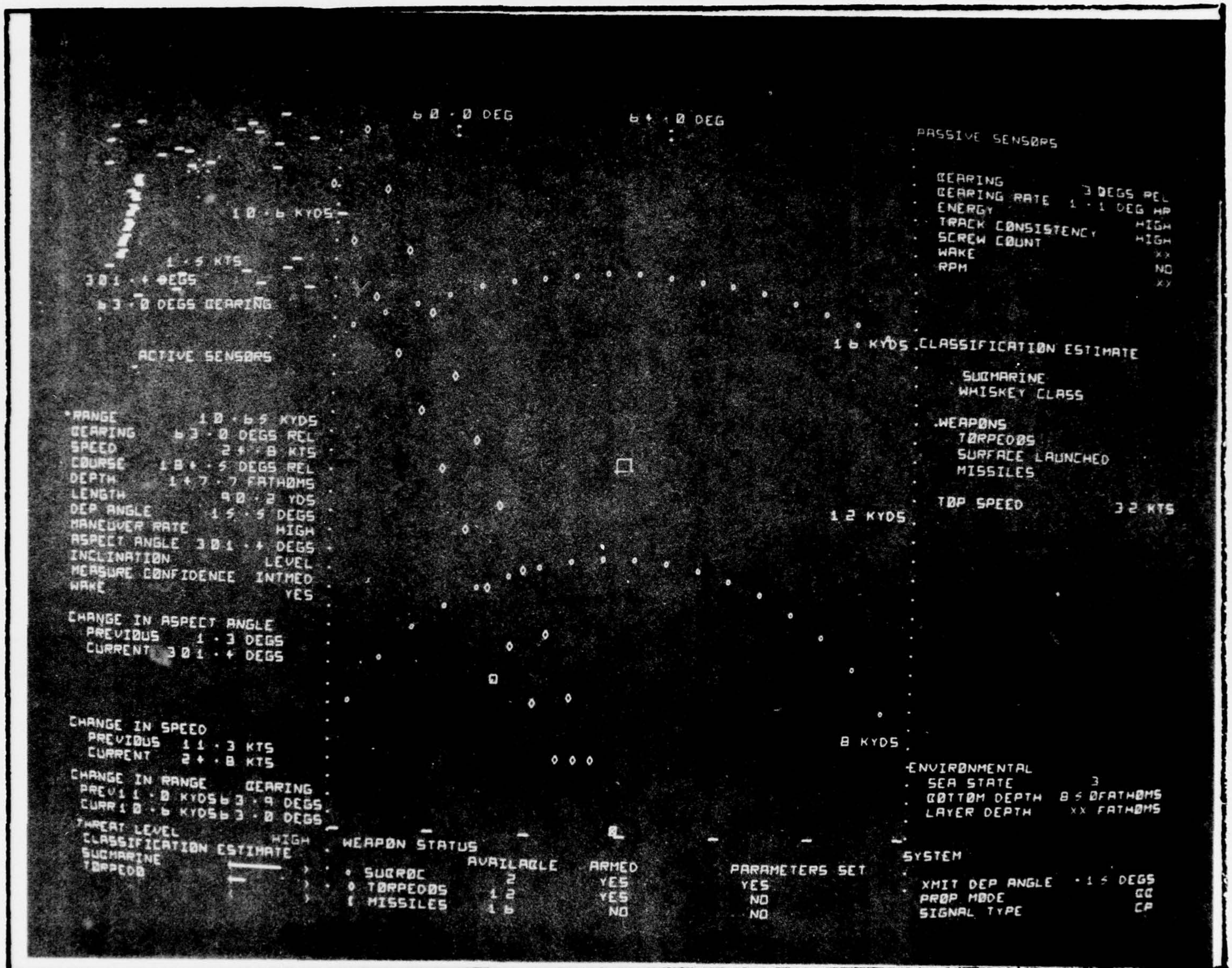


FIGURE G-20. Command and Control/Fire Control, Eighth Ping.

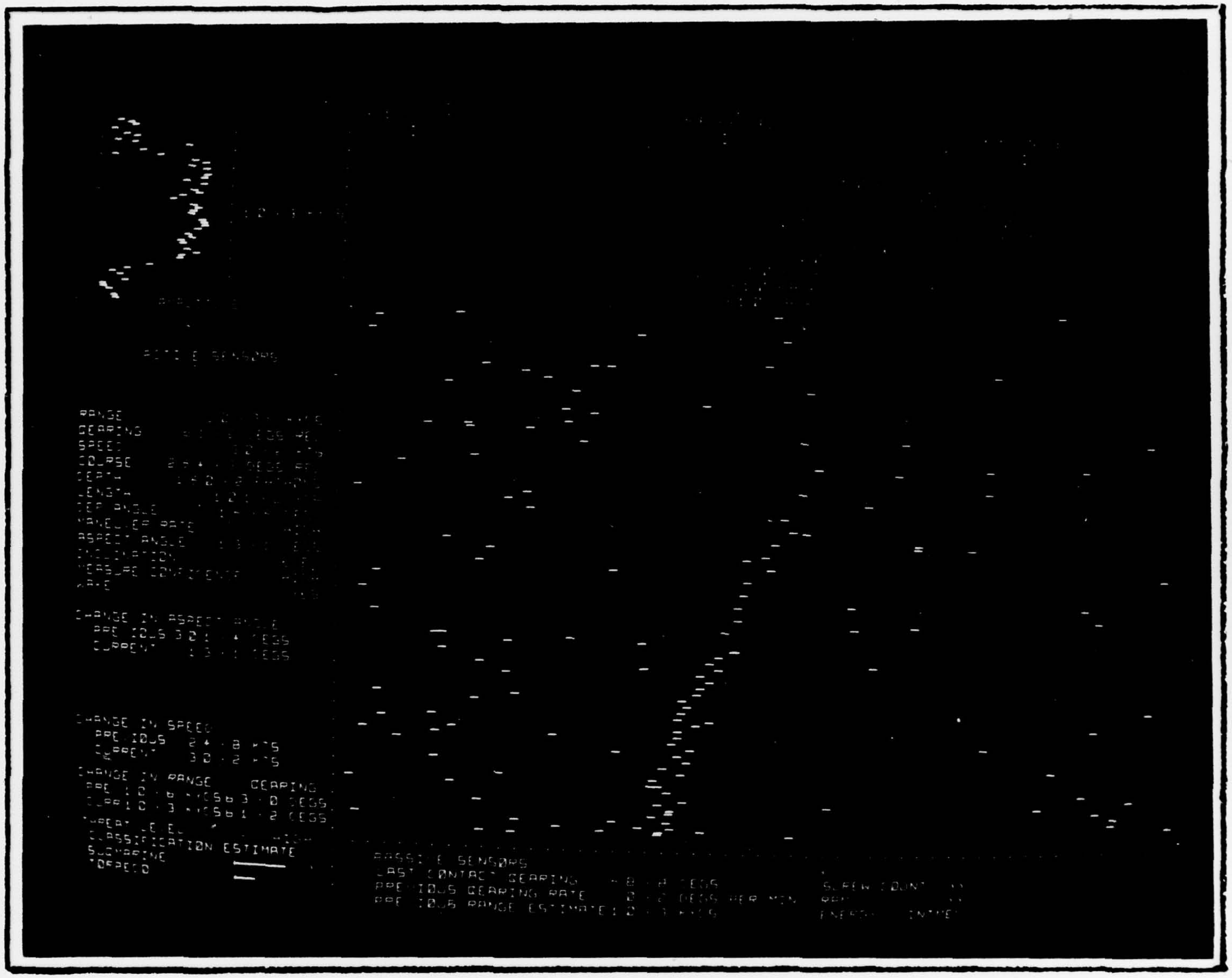


FIGURE G-21. Passive/Active Track History, Ninth Ping.

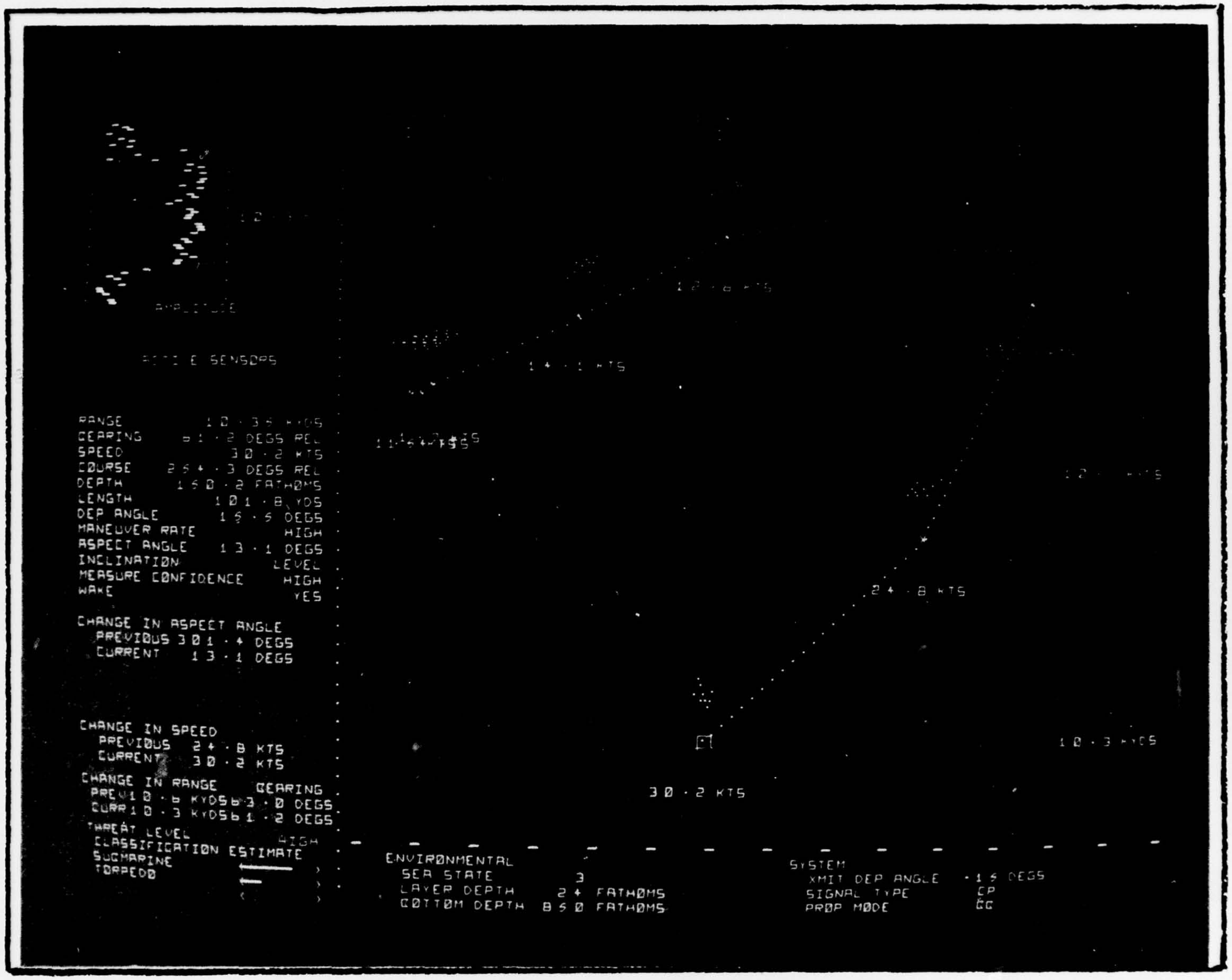


FIGURE G-22. Active Track History, Ninth Ping.

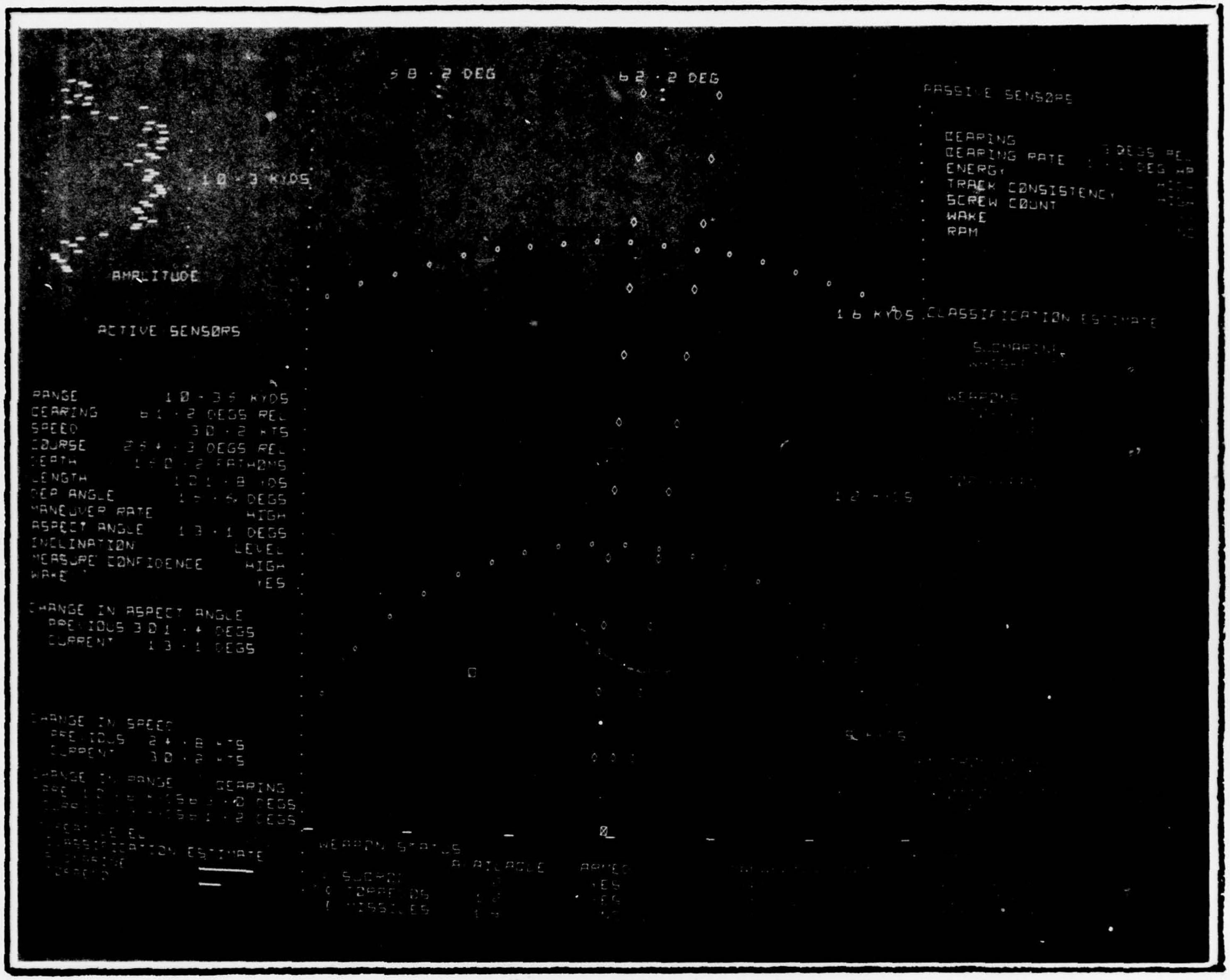


FIGURE G-23. Command and Control/Fire Control, Ninth Ping.

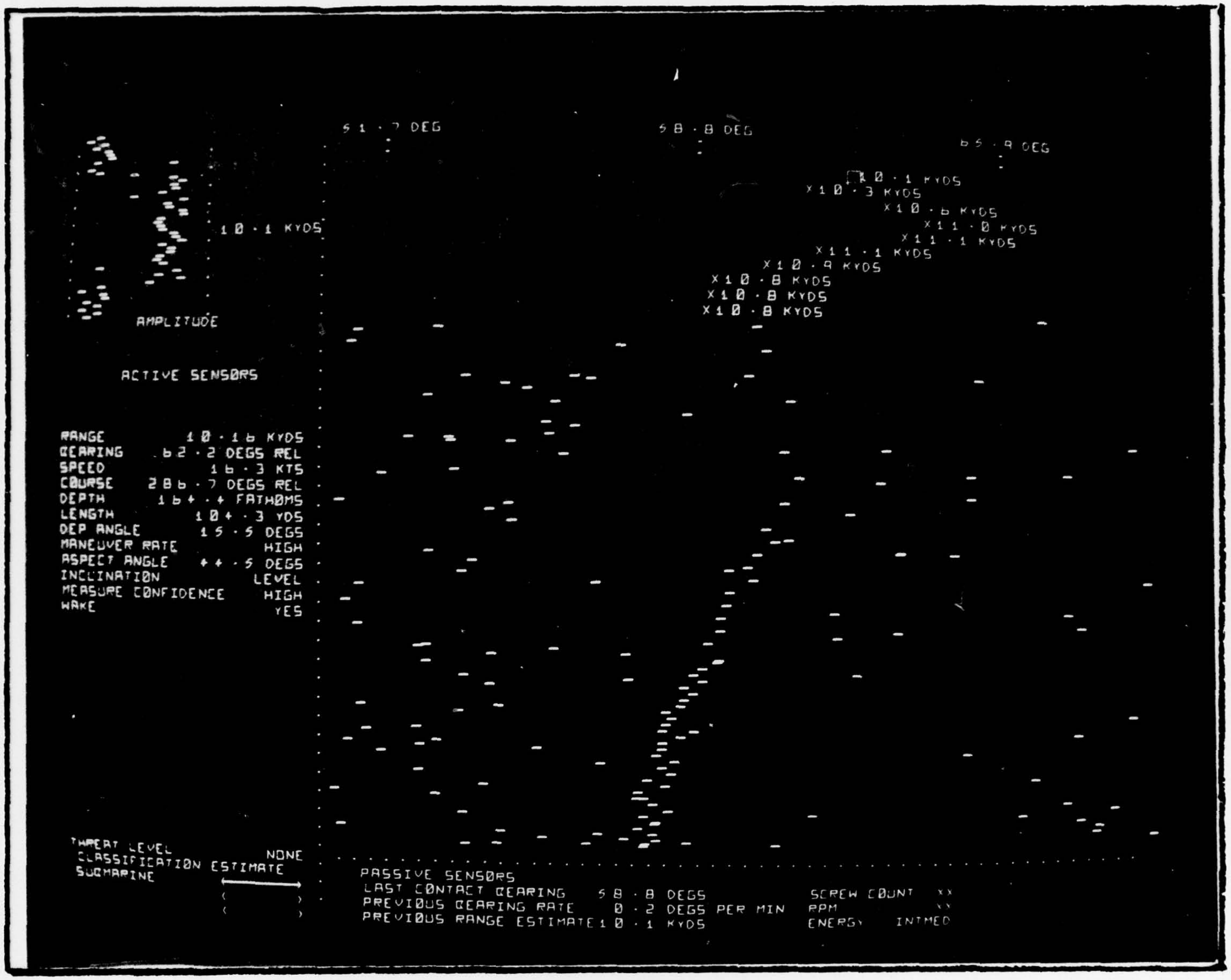


FIGURE G-24. Passive/Active Track History, Tenth Ping.

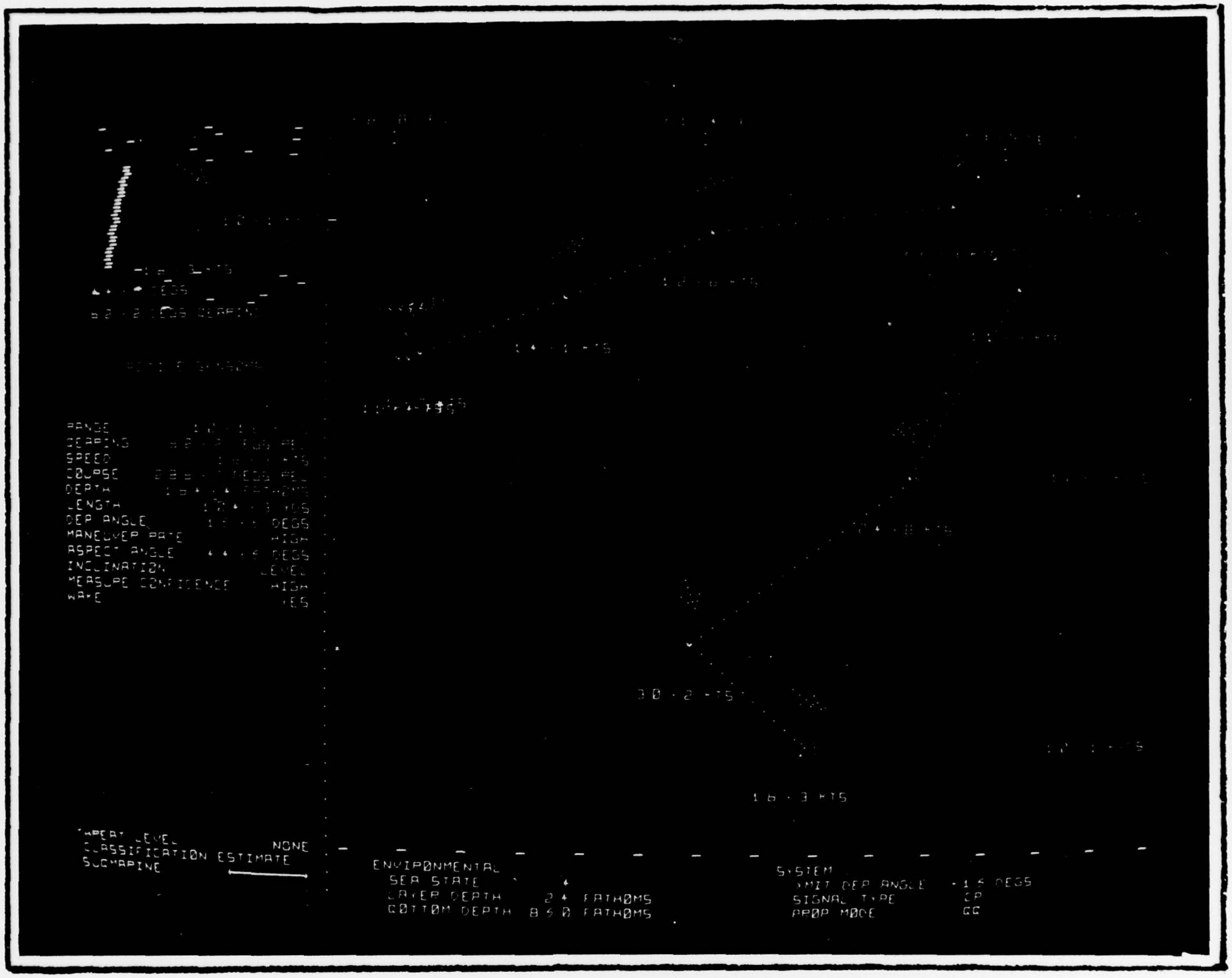


FIGURE G-25. Active Track History, Tenth Ping.

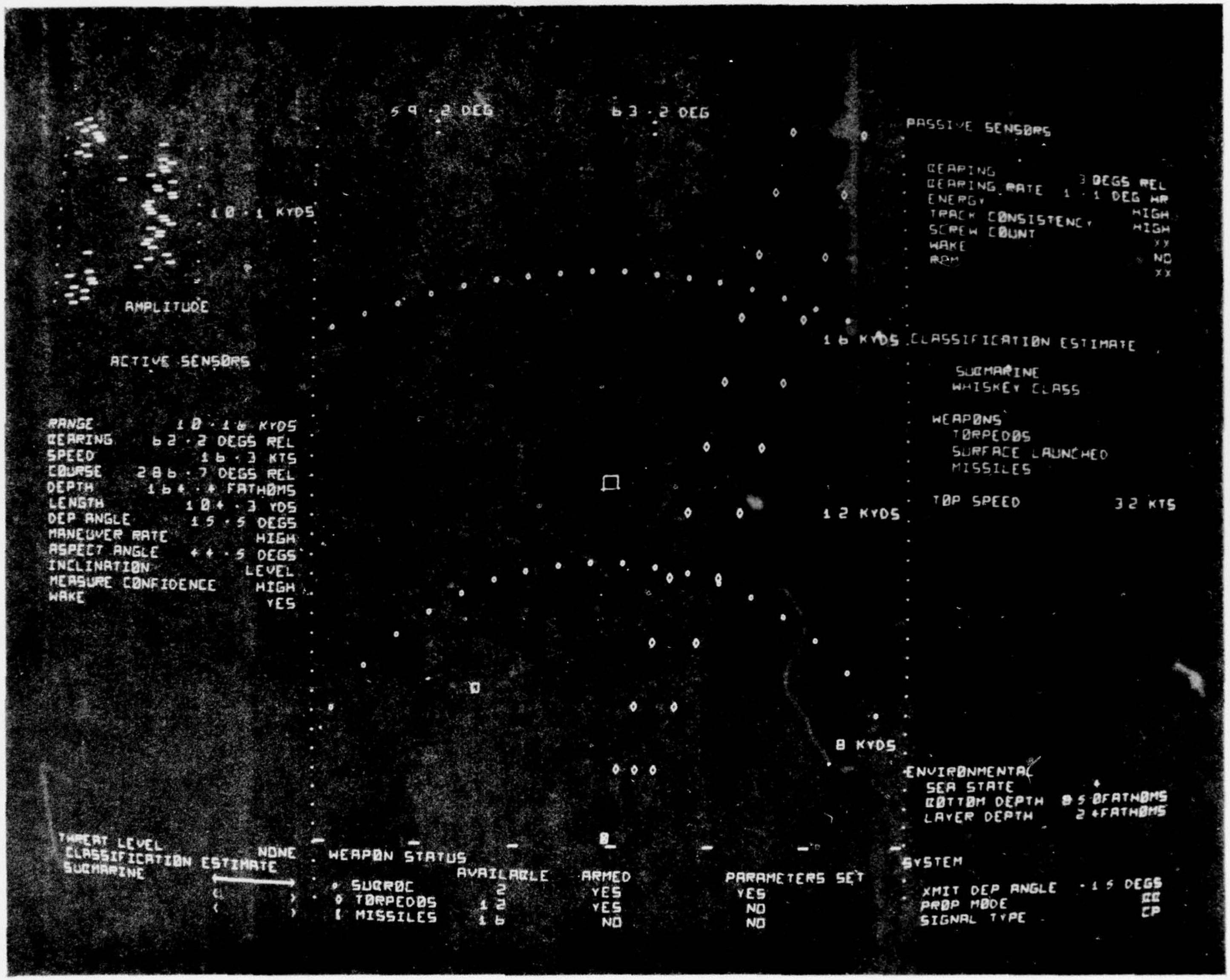


FIGURE G-26. Command and Control/Fire Control, Tenth Ping.

REFERENCES

1. Naval Undersea Research and Development Center Technical Note 542, An Approach to Target Classification by Computer in Advanced Active Sonar Systems, by J. A. Roese and G. A. Butler, June 1971.

2. Schindler, R.P., "Classification Clues in Long Range Sonar Systems, Proceedings of Symposium on Active Sonar Classification, Monterey, California, 1967, CONFIDENTIAL.

3. TRACOR, Inc. Report 65-421-C, Second Year Active Sonar Classification Studies, 18 December 1965, CONFIDENTIAL.

4. Navy Electronics Laboratory Report 1069, Determination of Sonar Bearing Accuracy with the Mark III LORAD, by G. S. Yee, 6 October 1961, CONFIDENTIAL.

5. Same as Reference 1.

6. Naval Undersea Research and Development Center Technical Note 479, Description of the Multi-Mode Display System, by J. A. Roese and D. A. Hanna, December 1970.

7. Naval Undersea Warfare Center Technical Publication 99, Simulation of a Digital-Coded Pulse Processor for Angle Estimation, by T. P. Norris, November 1968.